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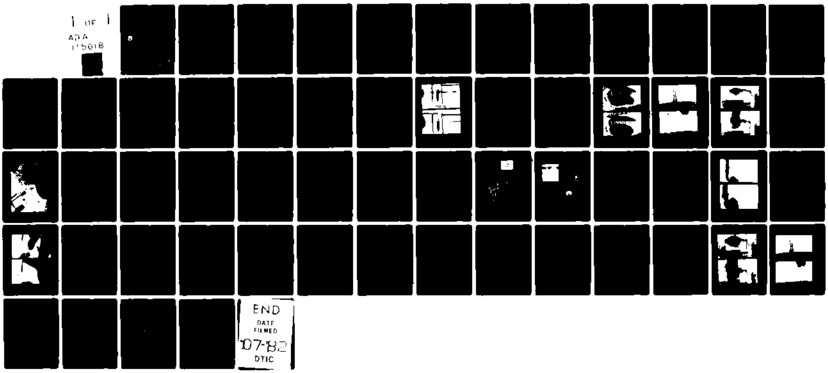

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ELECTROSTATIC TECHNOLOGY FOR CONTROL OF DUST AND HYDROCARBON VAPORS IN HIGH POWER LASER SYSTEMS

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April 1982

Final Report

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AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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The application of electrostatic techniques has been investigated as a repulsion system to keep dust off mirrors that might be used in high-power laser systems. A demonstration unit for a 30 cm mirror was built and shipped to Kirtland Air Force Base as part of the program.

Other efforts investigated the development of technology that might be used to keep dust and contaminants off large mirrors in an orbiting space platform. If

(over)

20. ABSTRACT (continued)

there is dust deposition it may be practical to clean the reflecting surfaces with a dry wipe-off system without damaging delicate coatings or metal films.

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I. INTRODUCTION

Studies with high power laser systems indicated that the presence of minute amounts of dust on optical components can result in severe damage to the reflecting surface when the laser is turned on. Recognizing that military operations cannot take place in a dust free environment, the United States Air Force supported a study of electrostatic technology as it might be applied to charge dust and "push" it away before it can deposit on an optical surface.

Another facet of the program concerned an examination of how this technology might be applied to larger (8 meter) mirrors in space environments, where the dust may be complicated by other contaminants (e.g., water) desorbed from the structural components or micrometeorites traveling a high velocity with respect to the spacecraft.

The primary objective was the development and testing of a dust repulsion system for a 30 cm mirror. This unit was to be shipped to Kirtland Air Force Base at the end of the on-campus test program.

A secondary objective was the investigation of technology that might be used for optical components in an earth orbiting space vehicle where the size of the elements involved precluded the use of liquid cleaning systems or the simple unit that was developed for the 30 cm mirror. Complicating factors to be aware of in the analysis included the presence of water vapor and/or chemicals desorbed from the vehicle structure and micrometeorites in the orbital environment.

A paper discussing the technology developed under this program has been approved by the Air Force and submitted to Applied Optics for publication. A copy of the paper is included as Appendix A to this report.

II. BACKGROUND DEVELOPMENT AND PARAMETRIC INVESTIGATION

The original idea for the dust repulsion system was based on earlier work performed under an Environmental Protection Agency contract [1]. In Figure 1, an example of a simple repulsion system is shown; Figure 2 shows the unit OFF and ON. When the system is ON, the smoke (ammonium chloride), at a flow velocity of some 100 m/min, was pushed backwards.

To adapt a technology of this type for mirror protection, a number of variables and possible designs must be considered. Typical questions were:

a. What is the optimum arrangement, in terms of needle-to-needle spacing, needle-to-screen distance and screen opening dimensions?

b. How shall the repulsion system be set up with respect to the mirror in order to achieve the optimum results in terms of dust repulsion, while at the same time remaining entirely out of the optical path?

To settle question a, it was necessary to build and test a number of needle-screen systems since there was no theory that could be used to predict the appropriate parameters. Fortunately, most of this work was performed under a program supported by the United States Army Tank-Automotive Command (TACOM), which had as its objective the development of a dust repulsion system for the turret blower on the M60-A1 main battle tank. The results of this work [2] demonstrated that a 25 mm needle-to-needle spacing and a 35 mm needle-to-screen distance would be most effective for dust repulsion, and these dimensions were chosen for the Air Force system.

The physical phenomena associated with a system of this type are of some interest in that there is an intense corona discharge from the high voltage (-17 kV) needles to the grounded screen as shown in Figure 1. This generates a large number of electrons that, in turn, attach to oxygen molecules to produce negative molecular ions. These ions are pushed through the open mesh of the grounded screen and produce the "electric wind" that helps keep back the dust particles. The ions serve an additional purpose in that they charge incoming dust particles, thereby encouraging their repulsion by the electrostatic field that penetrates the grounded screen. (This is an important factor because the large, 25 mm, screen openings allow the electrostatic field to penetrate and help form a barrier against dust particles with a negative charge.)

Another program in the laboratory concerned an investigation of techniques for keeping dust off astronomical telescope components by charging the dust and forcing it to deposit on an oppositely charged and sticky collector. A separate part of the same program was oriented toward new cleaning systems that might be used on large telescope mirrors without removing them from the mounting system. Both of these investigations were of value to the Air Force study and details are discussed in the following sections. We suggest that while these parallel programs may have had somewhat different objectives there was enough crosstalk between the various studies to permit significant savings of time and money, to the advantage of the overall effort.

III. EXPERIMENTAL RESULTS

Figure 3 shows a schematic drawing of the electrostatic dust repulsion system for the 30 cm mirror. The needle-screen array was designed to provide a significant charging and dust repulsion capability, while at the same time providing a large factor of safety for personnel in the vicinity.

One of the problems occurring in the testing of this new system was the development of experimental techniques to challenge the repulsion unit under conditions that approximated the actual conditions of service. One test of some interest was done in a 1 x 1 x 1 meter fiberglass box, as shown in Figure 4. Earlier studies had indicated that an input voltage of -17 kV at 10 mA would provide adequate dust repulsion and these conditions were chosen for the initial experiments.

For the first test, a small quantity of AC Fine dust* was laid in front of the fan outlet inside the test cell. The cell was sealed and the fan was allowed to run for 10 hours. At the end of that time the system was opened and photographs were taken of the glass plate for comparison with earlier photographs taken before the test began.

The test was then repeated with the electrostatic system ON. After about 1 hour of operation a look into the test cell indicated all the dust had disappeared. The cell was opened and it became clear that the electrostatic dust repulsion system had not only kept the dust off the 30 cm glass plate, it had charged the dust and forced it to deposit on the interior walls of the chamber. This result was unexpected, but it implies that the electrostatic system can actually remove dust from an area rather than simply repelling it from a surface.

When the test cell was opened there was a strong ozone odor. It was noted earlier that the intense corona discharge would produce ozone, but this was not expected to be a problem in the proposed Air Force application. There was some evidence of an odor that one of the technicians identified as associated with the plasticizer used for construction of fiberglass tanks and it is suggested the ozone had attacked the interior wall of the test cell. There was also some evidence of a vapor deposit on the Plexiglas windows of the test cell, but not on the 30 cm glass plate suggesting that, here again, the electrostatic system had charged and rejected the material.

In view of the rapid loss of dust when the repulsion system was ON, it was decided to remount the small squirrel cage fan inside the fiberglass box and make provision for periodic injection of dust.

To demonstrate that the dust was actually kept away from the optical surface, a 30 cm glass plate was set up in the mirror mount with the idea that the plate would be photographed before and after the test to qualitatively measure the dust density. For these tests, one-half of the mirror was masked with paper while the other half was exposed to the ambient dust level in the chamber. Figure 5 shows photographs of the glass plate after the power OFF and power ON tests; in both cases the left hand side of the glass plate was shielded and the right side was exposed. In the power OFF case there was quite a bit of dust on the exposed side; with the power ON there were some large (80 to 100 micrometer) particles that could not be repelled by the electrostatic field, but there was an almost complete absence of smaller material indicating the unit had operated as expected.

For the next series of tests a medical nebulizer was utilized to generate oil smoke. The oil (UCON, from the Dow Chemical Company) was used because of its high flash point and the knowledge that there is always the danger of accidental sparks that could ignite oil vapors. The resultant oil smoke consisted of very small (e.g., 1 micrometer) particles. Several accidental sparks did occur during the tests, but there was no indication that oil smoke had been ignited so it appears that the choice of the UCON material was appropriate.

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*AC Fine is the material normally used for testing air filters. It is a mixture of clay and silica ranging in size from 0.5 to 80 micrometers. The mass median diameter is 8 micrometers.

The test itself was essentially a repeat of the previous work with dust, but it was found impossible to photograph the oil droplets on the glass plate. The plate was replaced with a 30 cm cardboard disc, painted white, and once again significant deposition was observed with the rejection unit OFF, but very little with the unit ON.

We felt that these experiments demonstrated the ability of the system to reject dust and oil vapor in what might be called a "quiet environment." However, there was some interest in studies with significant ambient air movement where the motion of dust and smoke could be more effectively photographed. For these first experiments the system was set up in the laboratory so that dust could be dropped from a modified flour sifter to fall toward the 30 cm mirror.

Figure 6 shows two photographs taken of the test system with dust (AC Fine) falling toward the unit. In the upper photograph, the unit was OFF and the dust fell onto the 30 cm glass plate that simulates the mirror; in the lower photograph, the system was ON and the dust was rejected.

A second series was set up to meet the contract requirement concerning rejection of windborne dust. A small air moving system was used to provide the airflow and an ammonium chloride smoke generator was set up to permit flow visualization. In Figure 7, two photographs of the system ON and OFF are shown, at a wind velocity of 300 FPM (91.2 m/min). When the system was ON the smoke was rejected and we feel this may be the limiting wind velocity for a device of this type where there is no possibility of any element in the optical path itself.

The experiments discussed above have demonstrated the qualitative characteristics of the repulsion system, and that the next step would involve more quantitative studies, using a laser dust measurement system designed and constructed by Professor W. Wolfe's group in the University Optical Sciences Center.

Apparatus

The dust monitoring system is shown schematically in Figure 8, and in a photograph in Figure 9. The optical detector was a model SD-100-41-11-231 integrating photodiode, manufactured by Silicon Detector Corporation of Newbury Park, California; the electrical system is shown schematically in Figure 10. The laser was a 2 mW, model 145-01 helium neon unit manufactured by Spectra Physics Incorporated, Mountain View, California; the laser light was chopped mechanically at a rate of 50 Hz.

Experimental Procedure

For this study, the repulsion system was returned to the 1 x 1 x 1 meter box. The laser light source and the optical detector were set up at the specular angle, but care was taken to insure the detector was off axis and did not "see" the specular reflected light. Personnel from Optical Sciences Center had suggested that the intensity of the scattered light would be the best measure of the build-up of dust on the optical surfaces.

For the initial studies, the electrostatic dust repulsion system was set up inside the 1 x 1 x 1 meter fiberglass box as shown in Figure 9 with the idea that the dust injection and circulation system would be used to provide a dusty environment. To monitor the dust collected on the "mirror" a plastic petri dish was cleaned, dried, and weighed in a microbalance. The dish was laid on the 30 cm glass plate that simulated the laser mirror; the light from the He/Ne laser was allowed to hit the dish, as shown in Figure 9, where some dust had been suspended in the air to show the incident laser beam. This system was successful in that it demonstrated the ability of the detector to receive and measure light scattered by the dust in the dish. However, as the experiment was repeated it was found that the polycarbonate petri dish acquired a strong, nonhomogeneous electrical charge that interfered with the deposition of a smooth layer of dust.

To solve this problem, a glass microscope slide was substituted for the petri dish and proved quite satisfactory. For each test the slide was cleaned, weighed, exposed to the dust while being illuminated by the laser system, weighed, cleaned and then weighed again to check on the original clean weight. In each case the change in optical scattering was measured just before the slide was removed, and the graph in Figure 11 demonstrates the increase in slide weight versus the change in detector signal level.

These data have several interesting aspects. First, the system is quite sensitive, even in its present crude form, and it is interesting to speculate about the potential particle detection capability without consideration of any variation in scattering with particle size. At present, the smallest division on the curve of Figure 11 is 500 micrograms. If one assumes that system improvements would allow detection of a 1% change in scattered light, the effective sensitivity would be 5 micrograms. If it is assumed that this quantity of dust is spread uniformly over the 76 x 25 mm slide, the weight per unit area will be 2.6×10^{-6} kg/m^2. If it is assumed all of the particles are silica spheres 1 micrometer in diameter, weighing 1.6×10^{-15} kg each, there will be a total of 3.1×10^6 particles or 1.6×10^9 particles per square meter. If the laser beam is 1/16 inch (1.59 mm) in diameter it will have a cross-sectional area of 2×10^{-6} m^2. If the particle density on the surface is 1.6×10^9 per square meter, the laser beam will actually detect some 3250 particles. For 10 micrometer particles the number would be proportionately smaller; ideally, only 3.25 particles would be in the laser spot.

Here, it should be emphasized again that the above analysis is highly speculative but it does suggest the laser system offers some potential for detection of dust deposition on optical surfaces. Discussion with personnel in the Optical Sciences Center has indicated that far more sensitive systems, using phase lock technology, have been evaluated and that more data can be provided if necessary.

Returning to Figure 11, note that the curve becomes less steep at the 1 mg level. If one assumes, again, that all the particles are 1 micrometer silica spheres there will be some 6.3×10^8 particles, each having a cross-sectional area of 7.8×10^{-13} m^2, to cover a total area of 4.9×10^{-4} m^2 or about 25% of the 1.9×10^{-3} m^2 available. This may represent the point at which absorption by particle-particle scattering occurs; but, for the moment, all that can be indicated is that the change in slope was repeatedly observed and may represent a phenomenon of some interest deserving further investigation.

This completed the studies of dust deposition with the repulsion system OFF. For the next investigation the dust injection and weighing process was repeated with the repulsion field ON. In this case, no increase in scattering signal was observed, but upon weighing the glass slide it was clear there had been a significant increase in slide weight. At first, this was puzzling; but upon examination of the slide it was clear that some particle agglomeration had occurred and that a number of the large agglomerates had fallen onto the collection slide. The problem here was twofold; in the test box the dust charge circulates around until it either falls out or sticks to the walls of the box. When the electrostatic repeller is ON, there will be agglomeration and some of the agglomerates will inevitably fall on the collecting slide. For this reason, it was decided to move the system out into the laboratory and compare a test slide placed on the center of the 30 cm glass plate with a similar slide that was placed in the same area.

The open air tests in the laboratory were quite successful. In one case, the slide that was exposed to the laboratory environment picked up some 2.06 mg of dust over a 24-hour period, while a similar slide in the protected area gained only 0.11 mg for a net improvement factor of 94.7%. The test was repeated a number of times with very similar results. We suggest that the only possible problem with the repulsion system is dust ingestion as discussed below.

In these experiments, it was interesting to note the electrostatic system had a significant suction capacity since air was pulled through from the back of the repulsion system and forced over the mirror, thereby keeping dust from depositing. This process was quite effective provided the ingested air was free of dust; if dust was present, it was agglomerated by the electrostatic system and fell onto the mirror. If the system is tested in a dusty environment, the back of the repulsion unit should be shielded with plastic to prevent ingestion of ambient dust. The plastic shield does reduce the electrostatic wind to a slight degree, but there is still a very noticeable electrostatic repulsion that keeps ambient dust off the mirror.

It would appear that electrostatic technology offers a simple and effective system for keeping float dust off optical components, without introducing any mechanical components that would block the light or interfere with operations. In this connection, a question was raised about radio frequency noise from the corona system. Tests with a commercial AM-FM receiver indicated there were no detectable signals over the 54-160 kHz AM band and the 88 to 108 MHz FM band. Certainly testing over the military band wavelength will be needed, but it is felt that, at worst, the problem will be no more severe than that observed with conventional spark ignition for internal combustion engines.

IV. APPLICATIONS TO OTHER OPTICAL SYSTEMS

Discussions with the project officer indicated an interest in the application of the repulsion unit to a sun/wind screen proposed for a large laser telescope assembly designed for use in a desert environment. A system, designed to fit in the existing sun/wind screen unit, is presented in Figure 12. This unit will repel dust, but does not prevent its accumulation. A unit that provides for effective removal of dust is displayed in Figure 13. Technology of this type has been tested in the laboratory and is available if a need arises.

An area of some interest is the protection of large optical components in an orbital environment where conventional cleaning with liquids is impractical. Figure 14 shows an 8 meter telescope that might be installed in an orbital observatory deployed from the Space Shuttle. A proposed protection system for this telescope is shown in Figure 15; the center electrode would provide a source of electrons to charge dust and push it toward a positively charged collector outside the optical path. Experimental and theoretical studies of this system are discussed below.

A problem with orbital optical elements is protection from materials outgassed by the supporting structure, particularly during ascent when the ambient pressure is dropping rapidly. At the same time, there is an interest in rapid degassing when orbit has been achieved so that equipment can be put into service. Figure 16 presents a schematic of the system, in which an electron emission system is elevated by the mechanical unit shown in Figure 17. The electrons themselves would be provided by the low voltage field emission unit device of the type reported in Reference 3 and illustrated in Figure 18.

A number of advantages exist in what might be called the Stanford Research Institute Field Electron System:

1. Electrons are produced at low (100 eV) energy so that focusing and direction of the beam will be quite simple. Once the beam has been formed and directed, it can be accelerated to the appropriate energy (e.g., 20 keV).

2. Large (mA) electron currents are available with relatively low power requirements for driving the system. This is in contrast to thermal electron sources, where some 100 watts of input power are needed to produce electron currents in the microampere range.

This need for large currents at controlled energy levels is based on a knowledge of the magnitude of the outgassing problem. Discussions were held with personnel concerned with outgassing of space materials from the National Aeronautics and Space Administration (NASA) and TRW, and copies of the appropriate documents were obtained. The best reference appears to be a NASA publication (4) that provides information about the weight loss and collected condensables (on a 25°C substrate) when the material under test is exposed for 24 hours to a vacuum environment at a temperature of 125°C. In one case, a typical graphite-epoxy material suffered a weight loss of 0.81% while the 25°C collection plate collected a total weight equal to 0.15% of the original sample. The difference between these two values is a measure of the loss of volatile hydrocarbons and/or water vapor, and we feel that it will be necessary to develop systems to keep these contaminants from depositing on optical surfaces.

We suggest that the electrostatic systems for the charge and collection of dust and/or water vapor will be effective for degassing and collecting materials that might otherwise deposit on optical components. Nevertheless, there is some evidence of a need for a protection system that might be deployed over a telescope mirror during the ascent phase when the outgassing will be most severe. The idea here is that the cover would be charged to a voltage and polarity applicable for repulsion of charged dust and/or water vapor/hydrocarbons degassed from the structure. One possible design for a protection system is shown in Figure 19, where the hoop shaped element would be unfolded over the mirror to deploy an array of a metallic tinsel that could be held at a high voltage to repel contaminants that might otherwise deposit on the mirror. When the system was ready for operation, the cover would be folded back out of the way to allow unimpeded access to the optical surface.

V. TESTS AND APPLICATIONS OF THE DUST CHARGING AND COLLECTION SYSTEM

For a laboratory test of the charging and repulsion system, a 20 mm rifle cleaning brush was set up as a source of electrons, and a silicone oil coated fake fur fabric was set up as a collector for the charged dust inside the 1 x 1 x 1 meter box. The electron generator was operated at -20 kV DC while the collector was held at +25 kV DC. The experimental set-up and data, taken with a Climet dust counter (courtesy of Motorola Semiconductor Products, Phoenix, Arizona) are illustrated in Figure 20. To visualize the operation of the system, a series of photographs was taken after the injection of laundry lint with the ionizer/collector OFF and ON. Results are displayed in Figure 21; in the upper photo, where the system was OFF, the lint simply floated in the air. In the lower photo, where the system was ON, the lint was collected and held on the sticky surface.

The application of this technology to a practical telescope system made use of a 24 inch Cassegrain telescope, shown in Figure 22. Protection was provided to the primary and secondary mirrors by an ion generator mounted on top of the secondary mirror driver and a dust collector on the inner side of the optical tube, out of the actual light path. Here again, use was made of fake fur materials coated with silicone oil for dust collection. Silicone oil has a very low vapor pressure so there is no danger of oil evaporation soiling the mirrors when the system is OFF. The unit was tested in the laboratory before installation at the Smithsonian Institution Mount Hopkins Observatory, south of Tucson. Typical photographs are submitted in Figure 23. In one case, the power was OFF and the dust (AC Fine) fell through the system. In the other case, the power was ON and the dust was collected. Both the ionizer and the collector operate at 25 kV and 1 mA for a total delivered power of 50 watts.

This unit has been installed on Mount Hopkins and tested for approximately two months. Dust collection appears to be adequate, but there has been some mirror contamination by silicone oil. Discussions with Dr. Carl S. Marvel of the Department of Chemistry concluded that silicone oil may not have been the optimum material. Its vapor pressure is low, but it does not cling to surfaces and it appears there has been some ejection of oil by the electrostatic field. Work has continued on improved collectors, and this effort is discussed below.

One problem with the fur collection system was the cost of the material, and the need for direct charging since the fur was normally mounted on a charged screen or plate held at high voltage by a DC power supply. This in turn required a large and clumsy safety enclosure to preclude the hazard of personnel injury. A more effective system would make use of a naturally charged electret material, and discussions of this application have taken place with the only company that manufactures electrets for the commercial market, Filtrete Corporation, Hawthorn, New Jersey.

Another system may make use of a normally nonconductive material (e.g., butcher paper or cotton cloth) that could be rendered partially conducting by coating it with a material normally used for control of static electricity. This concept was tested with Cling Free (TM) and it was discovered that it is indeed possible to make cotton cloth conducting enough to collect dust at +10 kV, while at the same time having a resistance low enough to preclude personnel injury. In one test, a 2 x 2 foot square of cloth was used as a collector at +10 kV, but the leakage current to ground was 0.3 microampere. This is far below the level at which any personnel injury would occur. In fact, the typical "tingle current" or threshhold for perception for a sensitive subject is approximately 500 microamperes [5], a current some 1660 times larger.

Figure 24 demonstrates how this system might be implemented in a clean room environment.* It is assumed that one or more negative ion generators have been installed to charge the dust and that the possitive collector(s) would be dispersed about the room to collect the charged material. The system of Figure 24 would allow the dirty collection paper to be drawn off and discarded.

A question here concerns the sticky coating. The Aeroxon Company, New Rochelle, New York, a manufacturer and distributor of flypaper, have provided samples of an adhesive coating that is expected to be used on the collectors. It spreads easily and remains tacky for long periods of time, even when exposed to the dry air in Arizona. Testing these concepts on the Mount Hopkins telescope unit in the coming months is anticipated.

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*This system was not developed on a federal contract and all rights are reserved to the inventor and the University of Arizona. A patent disclosure has been supplied to the University Vice President for Research. Inclusion of this drawing in a contract report does not imply any rights to use this technology without written permission of the University or its agents.

VI. CLEANING OF OPTICAL SURFACES

In view of the long history of telescope use it might be thought that the technology for cleaning had been developed, but it appears this is not the case. Under some circumstances, mirrors can be washed in situ but this becomes progressively more difficult as the mirror diameter increases. Chemical cleaning with solvents that will vaporize after use (e.g., Freon TM) has been used on a small scale; but, again, the problems with large telescopes, particularly in orbital systems, would be severe.

A number of investigators made use of air blowing systems to remove dust, but many experiments [6] indicated that small (e.g., 10 micrometer) particles cannot be removed by blowing because of the strong bonding to the substrate. In Reference 6, electrostatic techniques were used to remove some of the adherent dust; but, in spite of every effort, there was a residual dust coating that could not be removed without mechanically moving the dust to break the bond to the substrate. The problem here was moving and removal of dust without scratching the delicate optical surfaces.

We suggest this task is best approached by using the electret materials discussed above because they are soft and might be used to wipe optical surfaces without scratching, while at the same time having a very large electrostatic charge to hold the displaced dust and prevent redisposition. Some very small scale tests on freshly deposited aluminum films indicated that deposits of AC Fine can be completely removed without scratching the aluminum. It would seem this technology could be developed to provide an electret brush that would be passed over the optical system to remove dust and hold it until the collecting system can be taken out of telescope environment.

These concepts will have to be demonstrated on metal and dielectric surfaces before they can be approved for general application. One test might involve wiping a dielectric coated surface and then evaluating its optical properties over the wavelengths of interest.

VII. CONCLUSIONS AND RECOMMENDATIONS

The program objectives, in terms of a dust repulsion system for a 30 cm mirror system and a protection technology for larger (8 meter) optical elements, have been met. Section IV discussed the somewhat primitive optical system developed by the Optical Sciences group on campus. This unit was successful for the application at hand, but a need exists for a more sensitive and stable optical device that might be used to monitor dust deposition on optical surfaces. The proposed system is shown schematically in Figure 25, where the incandescent light is diffused by an optical system to illuminate a larger area than that exposed with the simpler system of Figure 8. If dust is present on the substrate there will be backscattering and this radiation will be collected and measured by an optical system.

This technology has a number of applications in military optical systems or optical coating technologies where the presence of dust will result in a defective film. It seems quite practical to scan surfaces in the vacuum system before coating is done, in order to be sure the surfaces are clean.

Another field of interest is the detection of chemical contamination that might interfere with the use of optical systems or result in corrosion damage over some period of time. The Oak Ridge National Laboratory demonstrated that ultraviolet fluorescence can be used to detect minute quantities of levels of hydrocarbon contamination on various substrates [7]. Again, the exploitation of this system might be part of a future program on dust control.

Additional research in these areas is recommended.

REFERENCES

1. Hoenig, S. A. "Use of Electrostatically Charged Fog for Control of Fugitive Dust Emissions," PB-276 645, National Technical Information Service (NTIS), November 1977.

2. Hoenig, S. A. "Electrostatic Dust Repulsion," Final Report Number 12572 to U. S. Army Tank-Automotive Command, Warren, Michigan 48090, Contract No. DAAE07-80-C-9033, (May 31, 1981). "Test and Evaluation Document distribution limited to U. S. Government agencies only. Other requests for this document must be referred to USATACOM, ATTN: DRSTA-TS."

3. Brodie, I., C. A. Spindt. "The Application of Thin Film Field Emission Cathodes to Electronic Tubes," Appl. Surf. Sci., 2, pg 149 (1979).

4. Campbell, W. A. Jr., R. S. Marriott, J. S. Park. "Outgassing Data for Spacecraft Materials," NASA N80-30441 (August 1980). Available from NTIS, Springfield, Virginia 22161.

5. Cromwell, L., et al. Biomedical Instrumentation and Measurements, Prentice Hall, Englewood Cliffs, New Jersey, pg 374 (1973).

6. Zimon, A. Adhesion of Dust and Powder, Plenum Press, New York (1969).

7. Gammage, R. B., T. Vo-Dinh. "Luminescence Monitoring of Oil or Tar Contamination for Industrial Hygiene," Nuc. Instrs. and Methods, 175, pp 236-238 (1980).

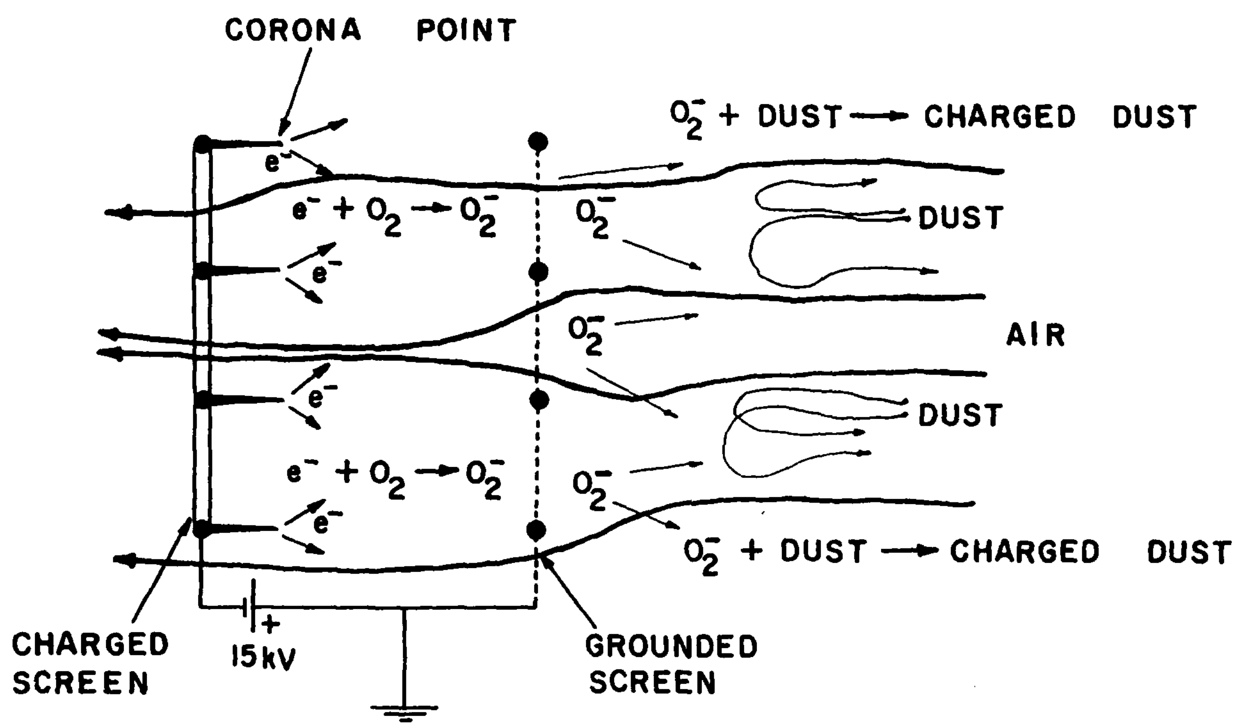
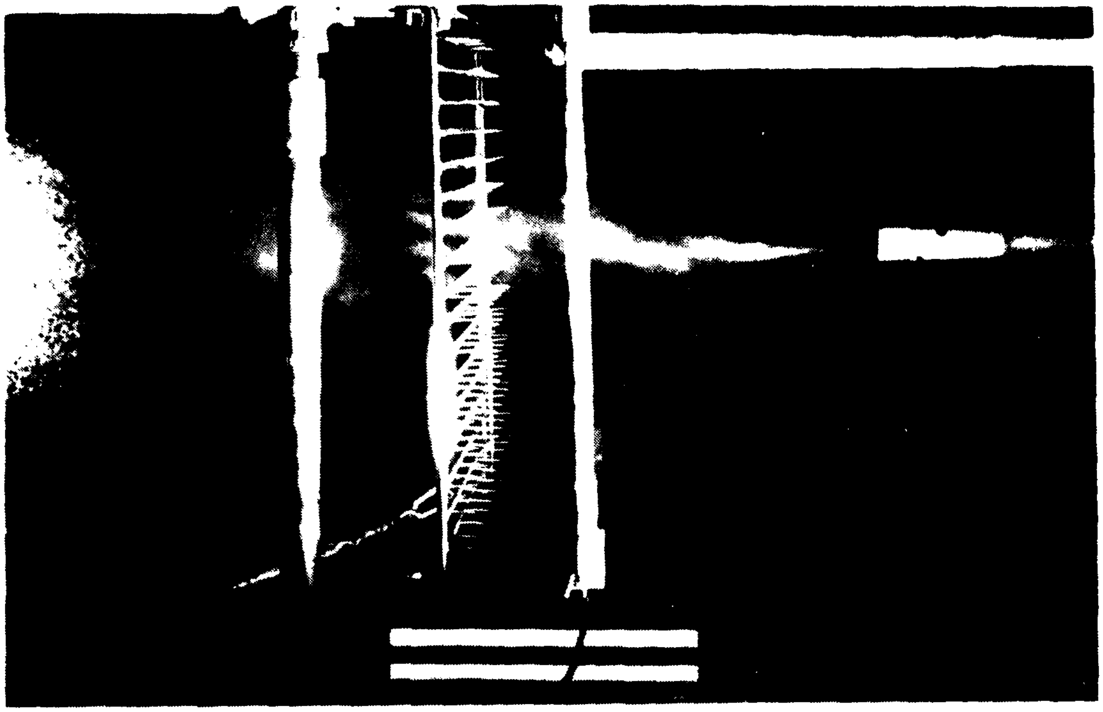
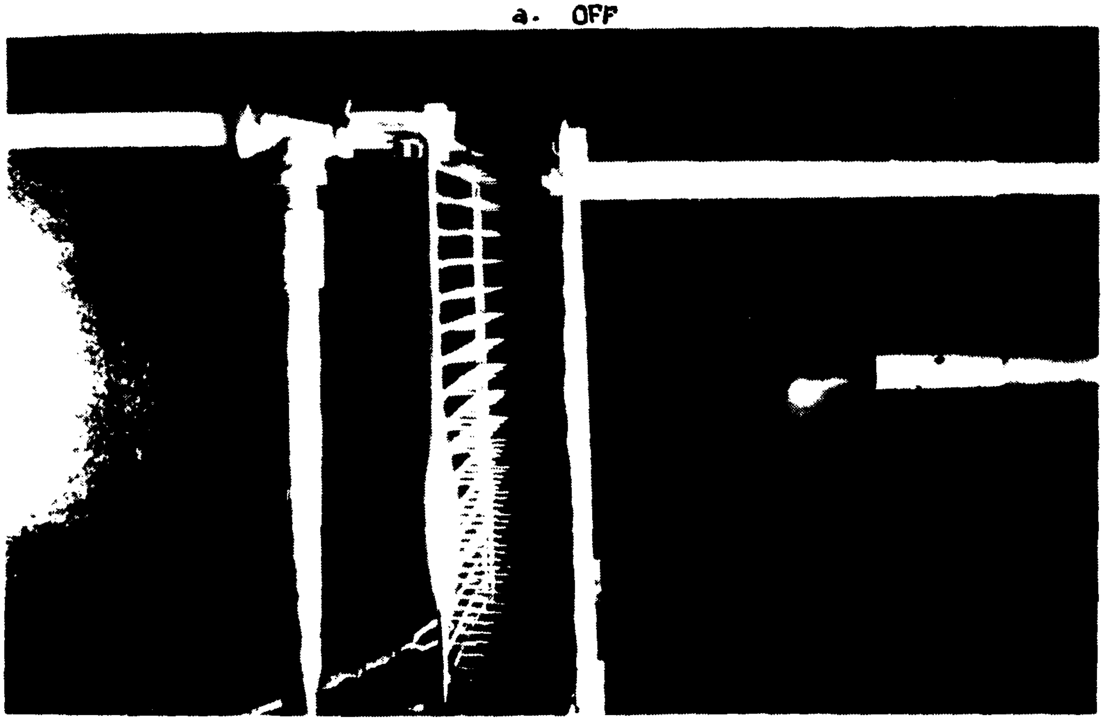


Figure 1. Schematic of Electrostatic Fence to Reject Dust and Admit Air.



a. OFF



b. ON

Figure 2. Electrostatic Fence: a. OFF; b. ON.

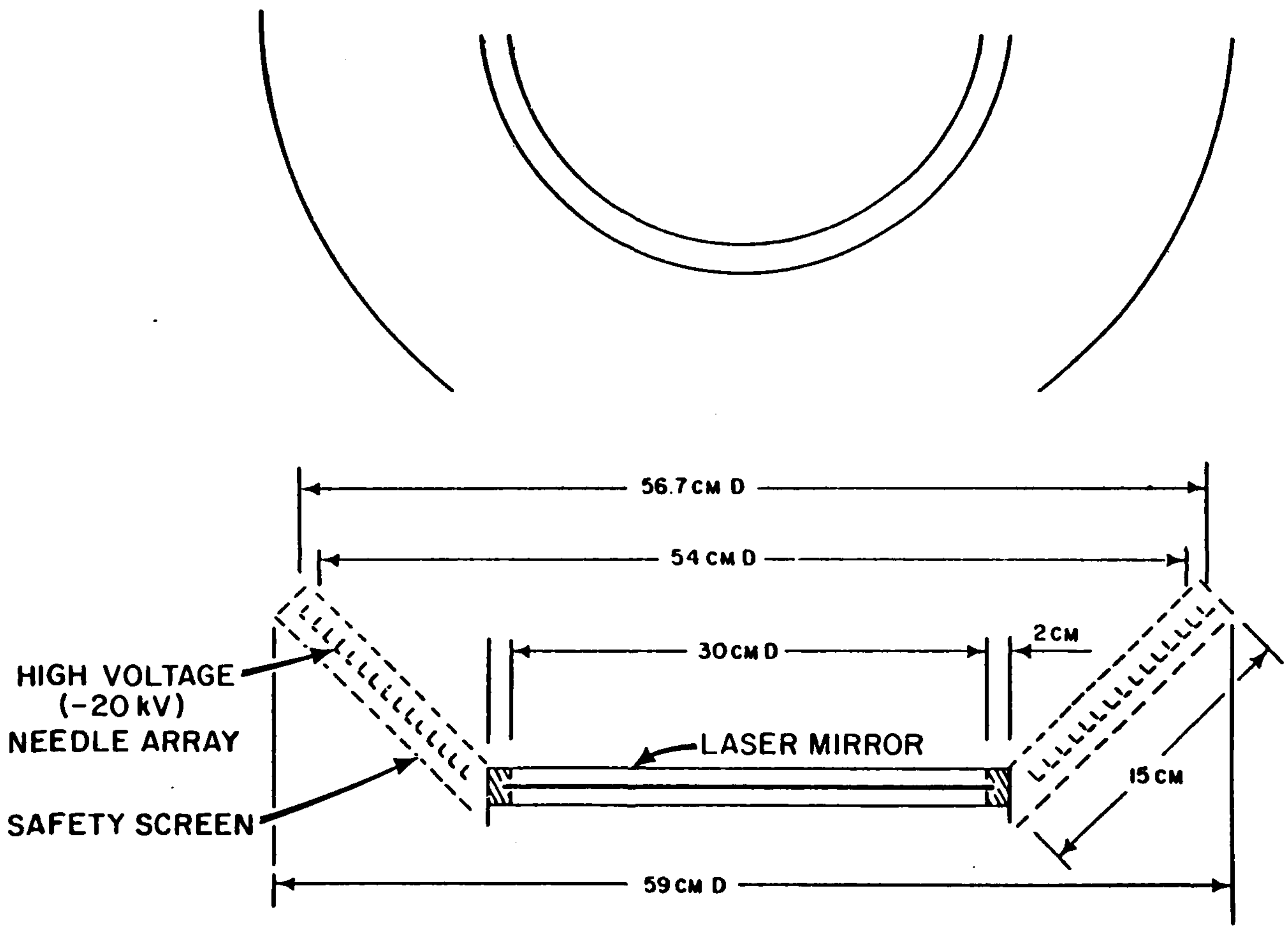


Figure 3. Schematic Drawing of Electrostatic Dust Repulsion System for 30 cm Mirror.

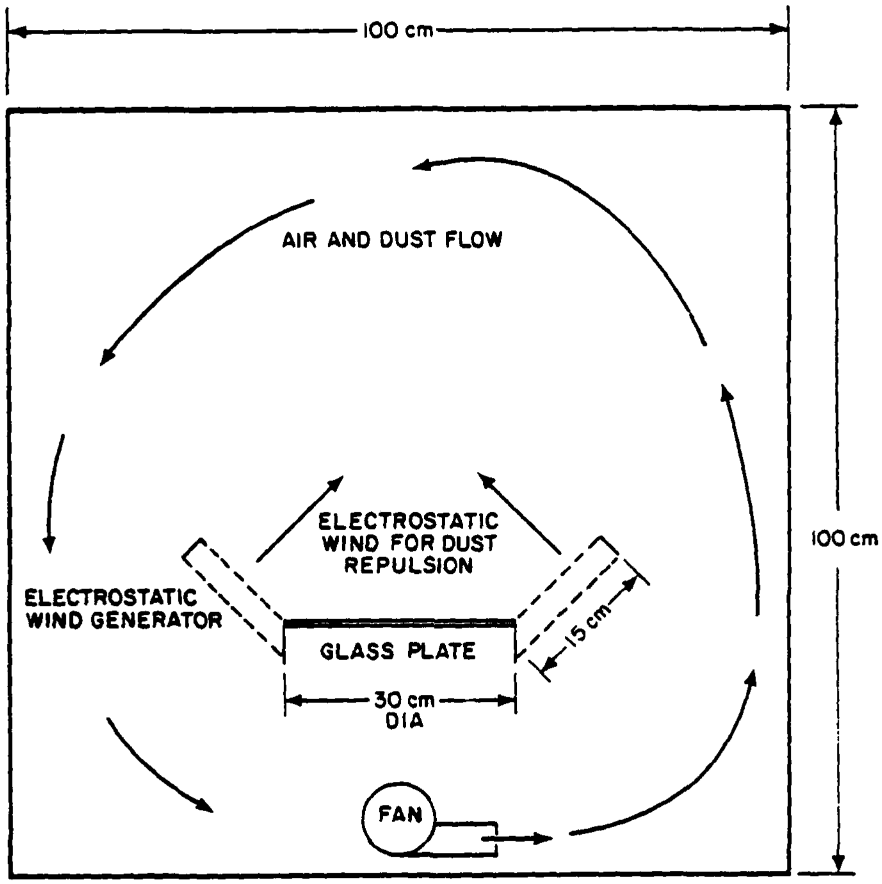
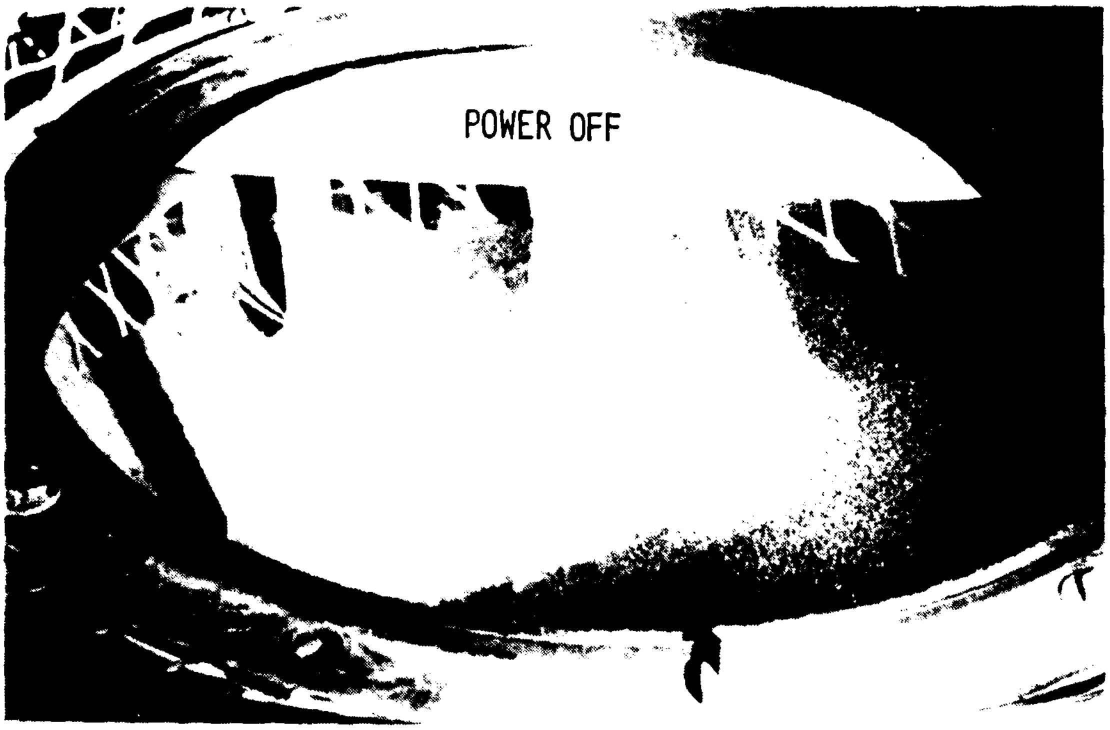
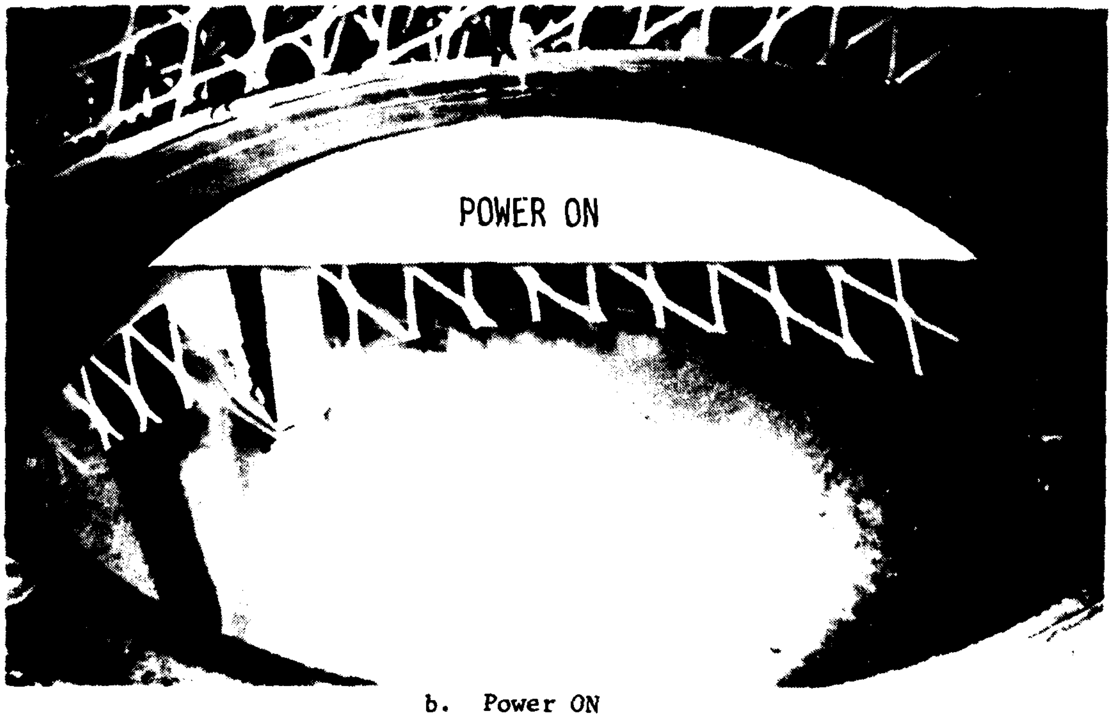


Figure 4. Schematic Drawing of Electrostatic Dust Repulsion Test Facility.

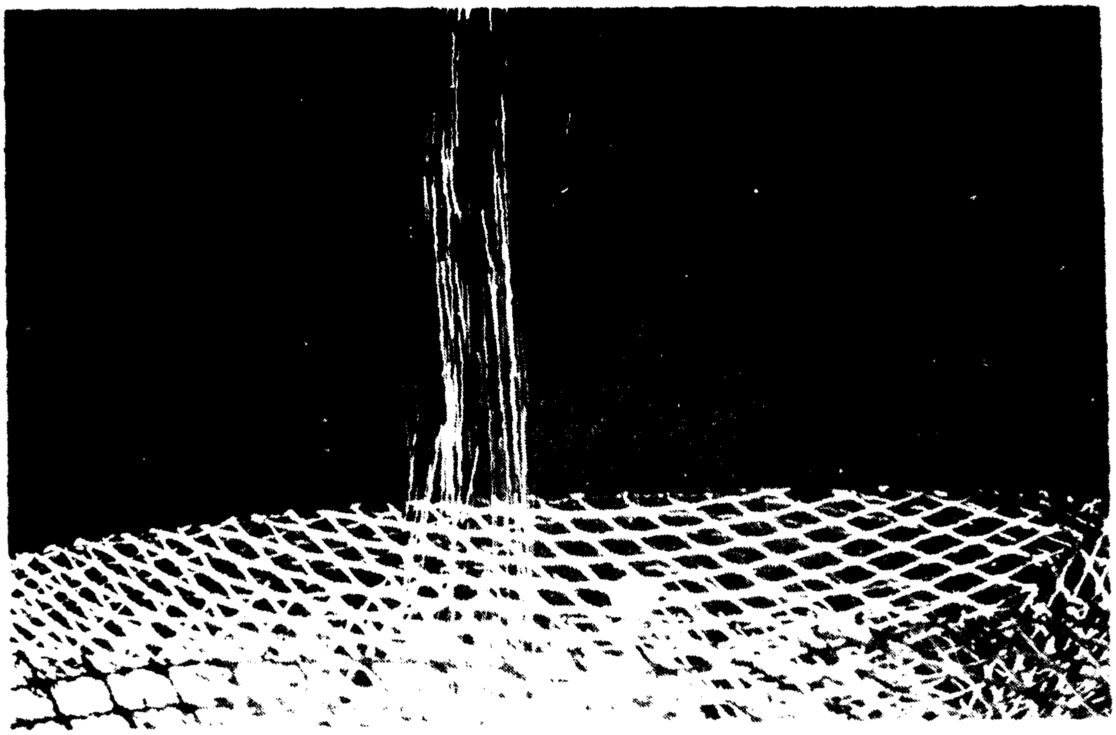


a. Power OFF

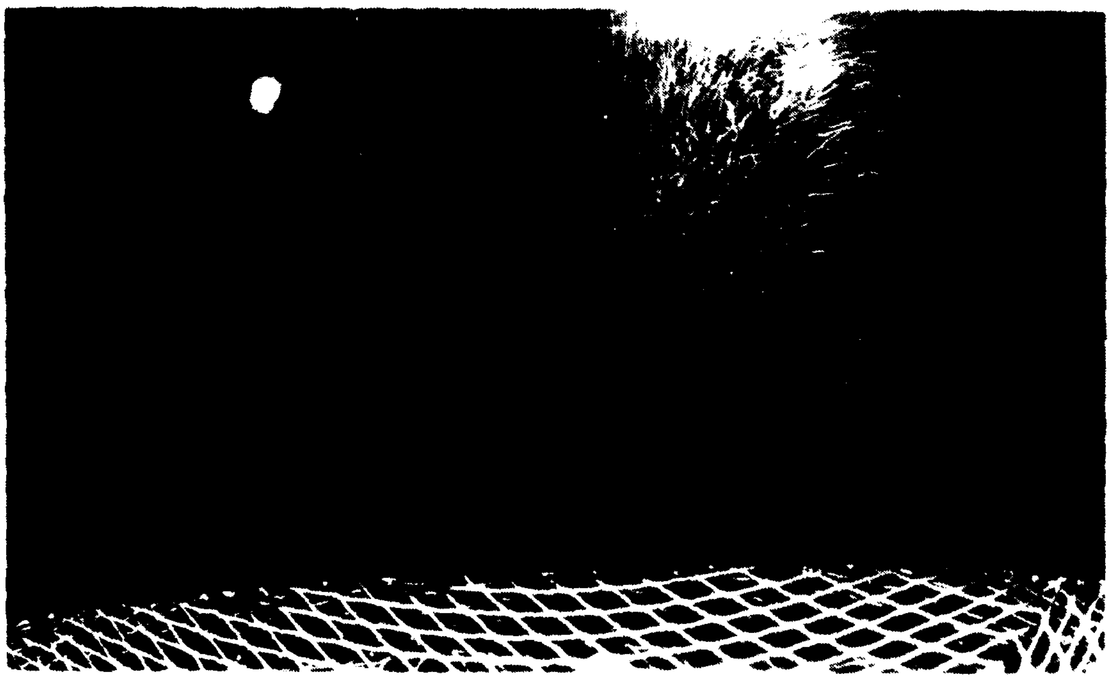


b. Power ON

Figure 5. 30 cm Glass Plate after Dust Deposition Test:
a. Power OFF; b. Power ON.

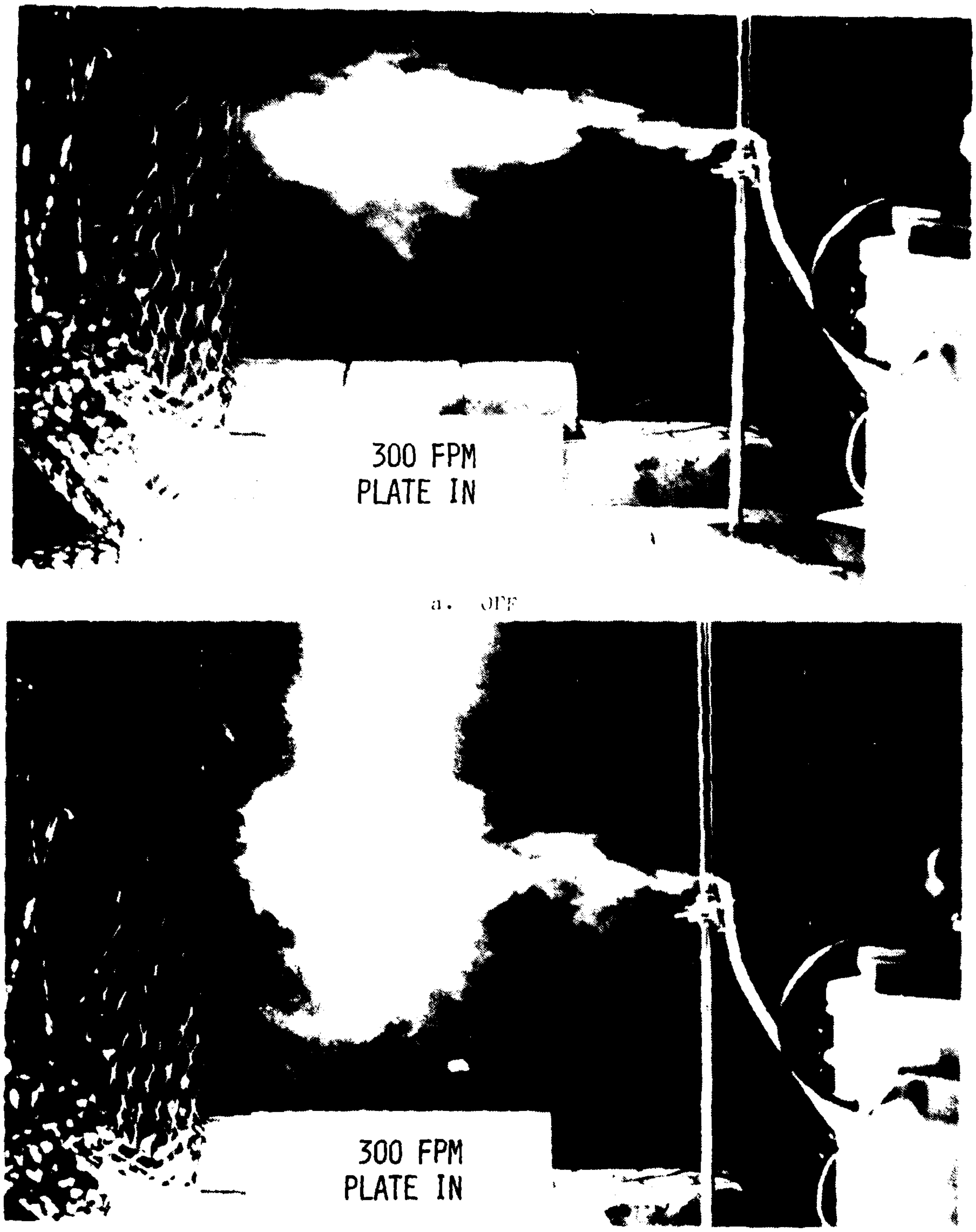


a. OFF



b. ON

Figure 6. Electrostatic Repulsion System: a. OFF; b. ON.



a. OFF

b. ON

Figure 7. Electrostatic Repulsion System: a. OFF; b. ON.

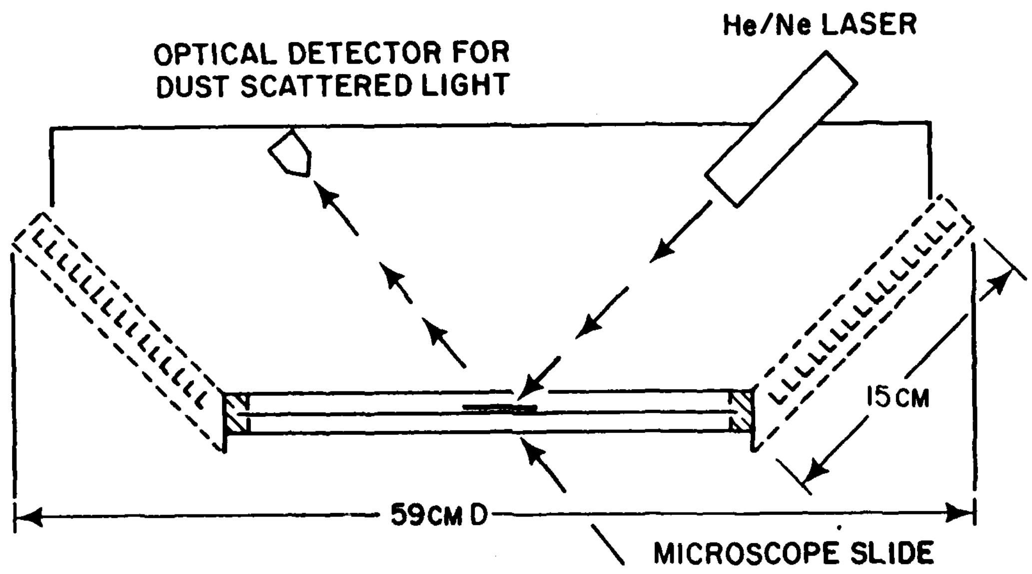


Figure 8. Schematic Drawing of Electrostatic Dust Repulsion System for 30 cm Mirror with Dust Monitor.

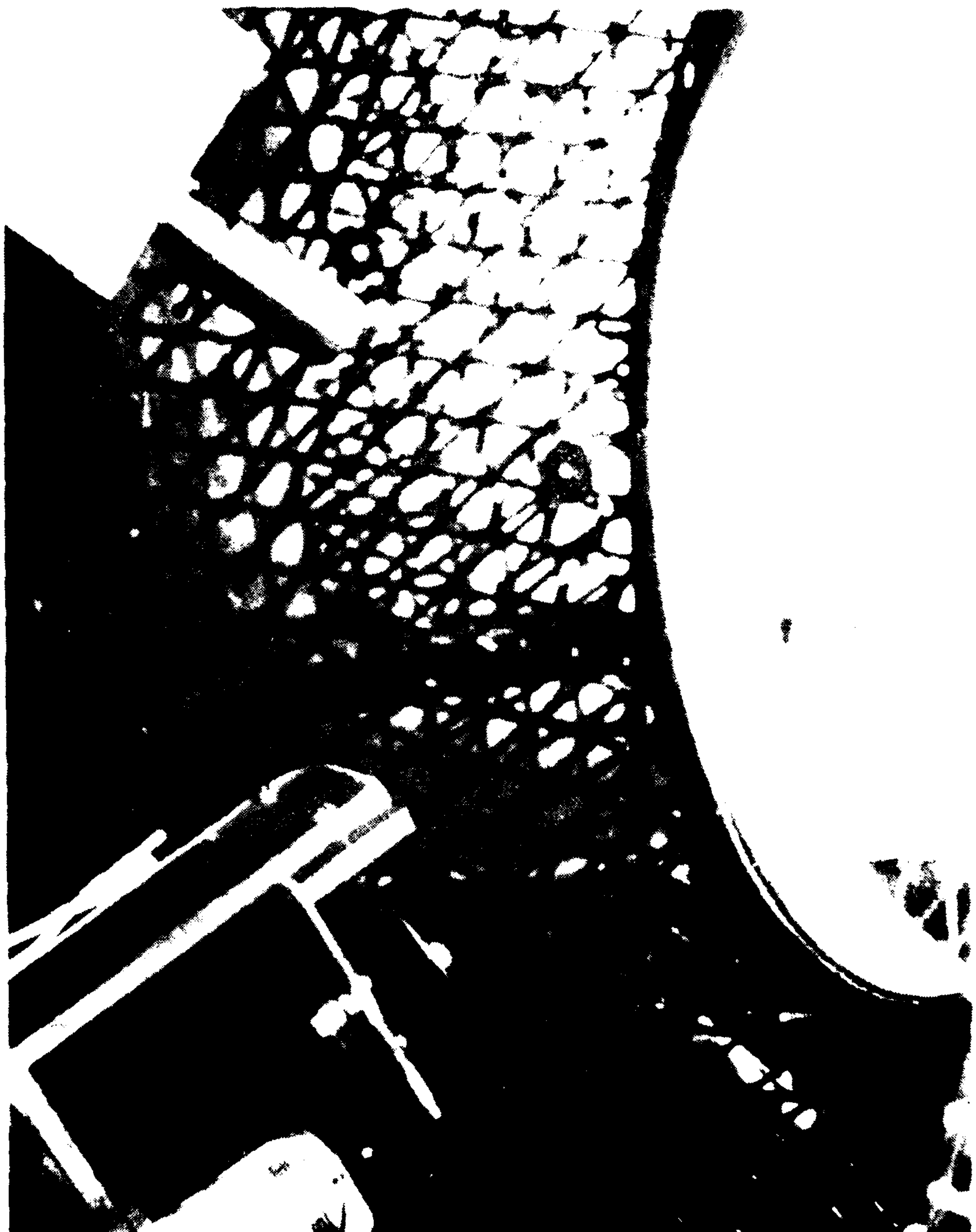
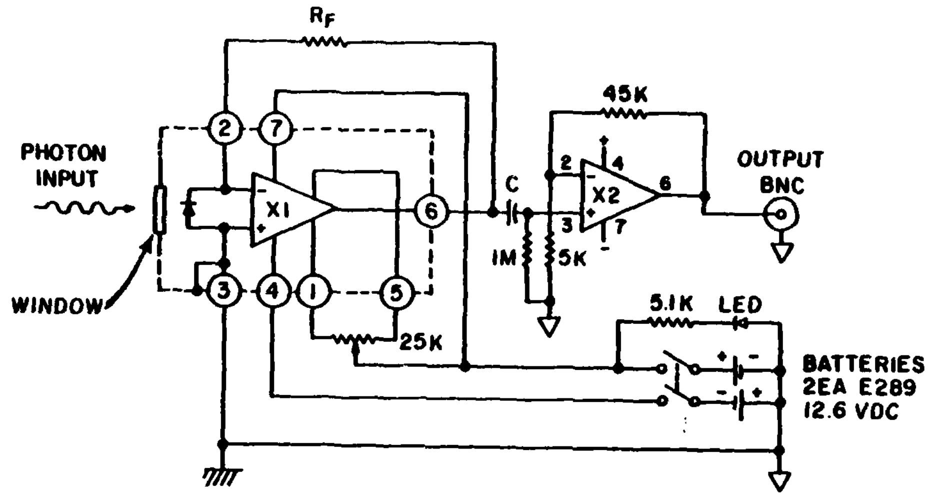


Figure 9. Laser Dust Monitoring System in Action.



4. C DET. BY CHOPPER FREQ. (IMF FOR 50HZ)
3. X2-TYPE 741
2. X1 = SDC TYPE SD-100-41-11-231
1. SELECT R_F FOR DESIRED OUTPUT (1000M)
NOTE

C-010 SHEET2
SCHEMATIC

Figure 10. Electrical Schematic for Optical Dust Detection System.

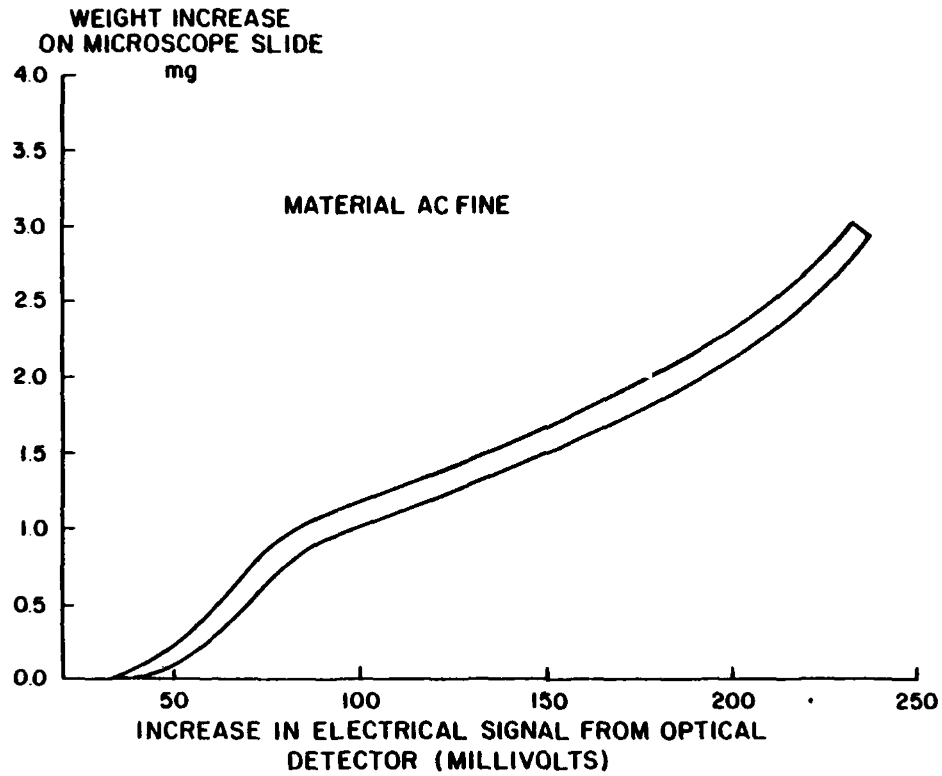


Figure 11. Laboratory Data Dust Build-up vs. Scattered Light.

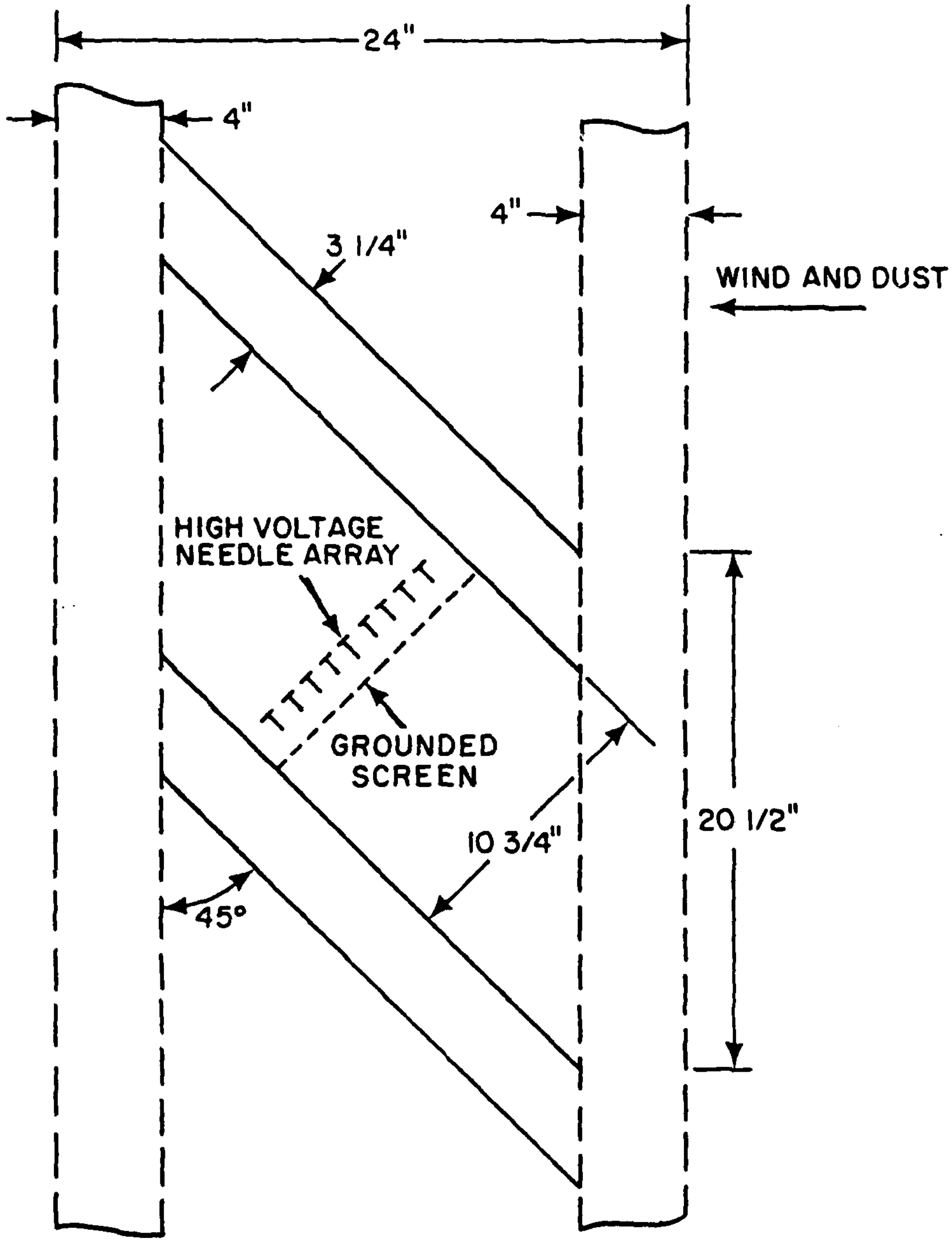


Figure 12. Schematic Drawing of Electrostatic Dust Repulsion System.

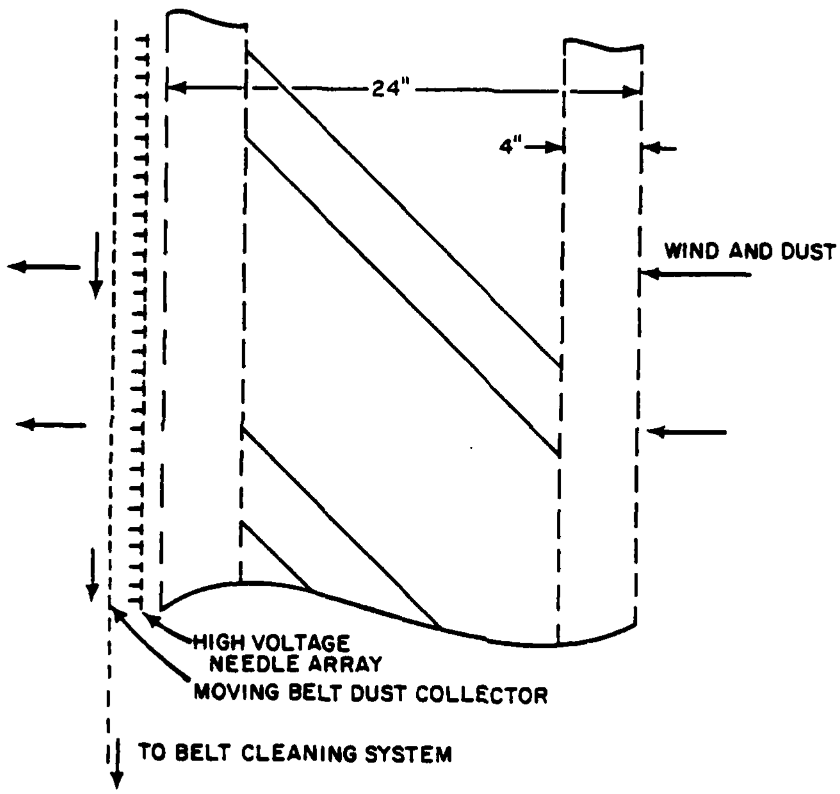
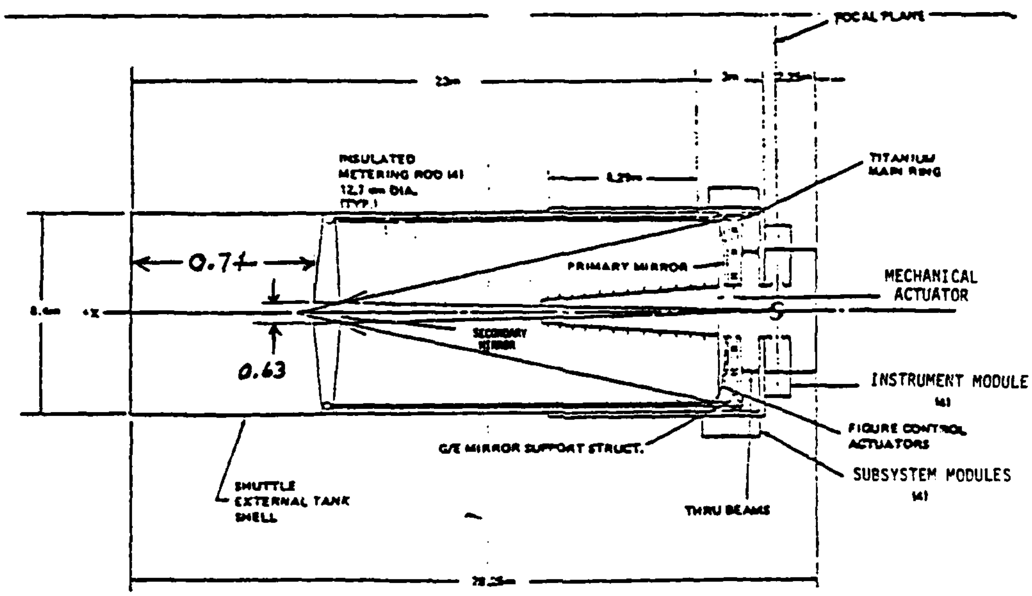


Figure 13. Schematic Drawing of Electrostatic Dust Control System for Aero/Fence Sun Shield.



VLST Ritchey-Chretian aplanat concept
8-m primary f/2.2
f/24 system

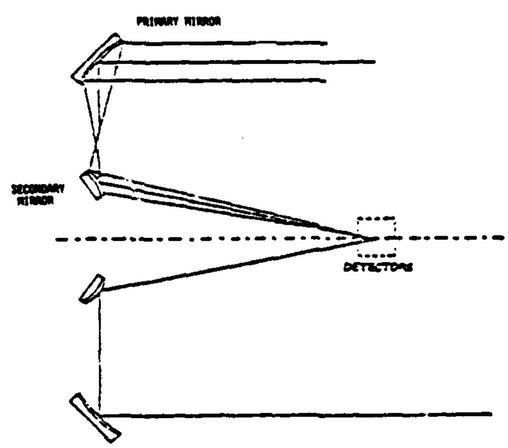


Figure 14. VLST Intermediate Incidence Aplanat Concept.

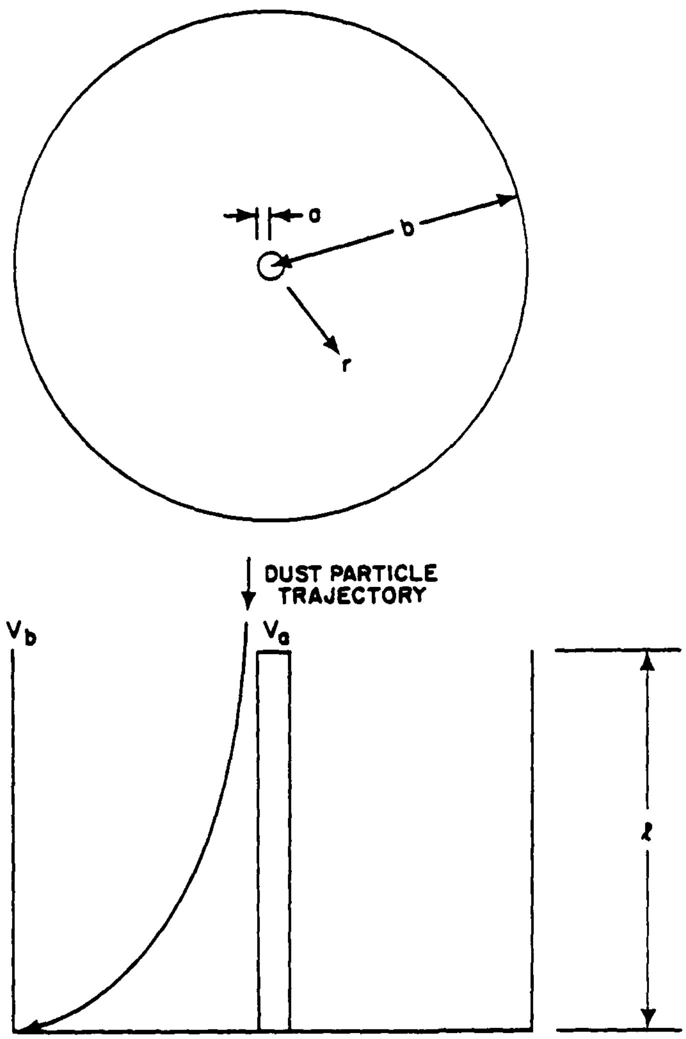


Figure 15. Schematic Drawing of Electrostatic Protection System.

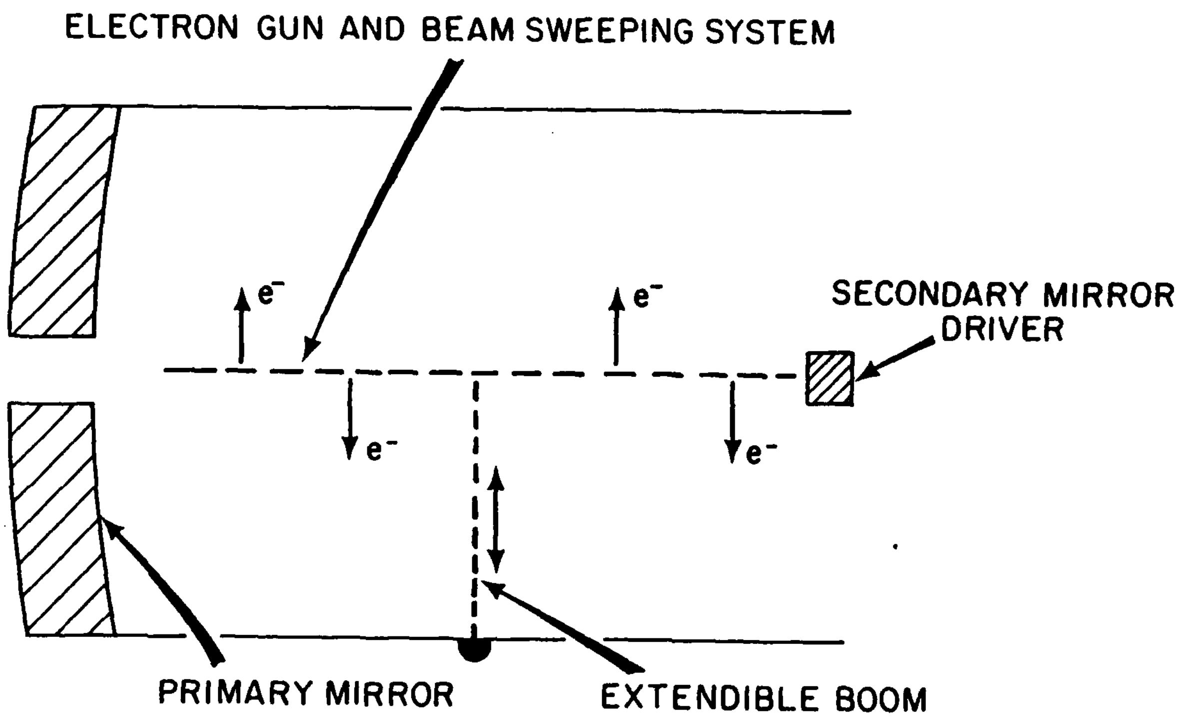


Figure 16. Beam Control System Concept with Added Electron Bombardment System.

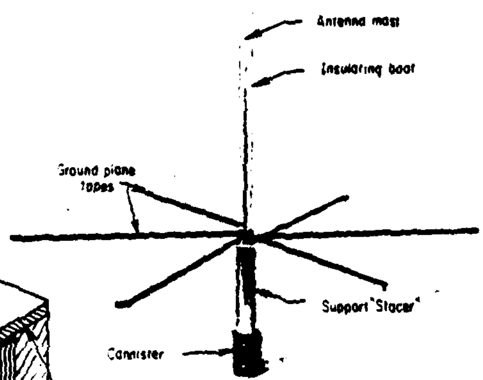
Canned Springs Unfurl Jack-in-Box Antenna

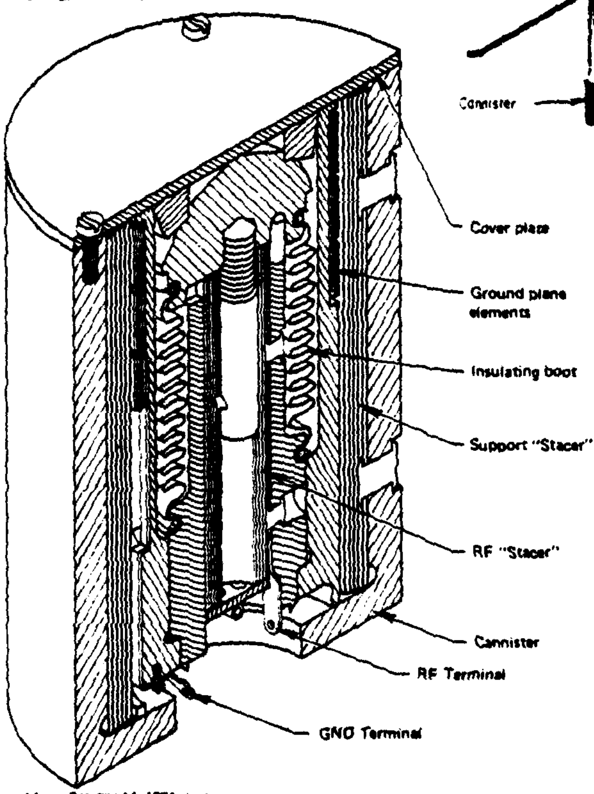
scanning the field for

NEW IDEAS

and products

An innocent-looking canister, 2¼ in. diam by 3¼ in., houses this self-extending military sending/receiving antenna. Basic stainless-steel spring elements that make this possible are a 1-ft-extending helical support strip (Stacer), six 18-in. ground-plane elements of ½-in. cross-curved tape, and a 1½-ft antenna mast (Stacer) covered by an insulating and waterproof polyethylene boot. Weight is only 1 lb. Since spring energy unfurls the mast, there's no need for an external energy source, such as in inflatable designs, reports the co-developers, Harry Diamond Laboratories, Washington, D. C. and Ametek/Hunter Spring, Hatfield, Pa.

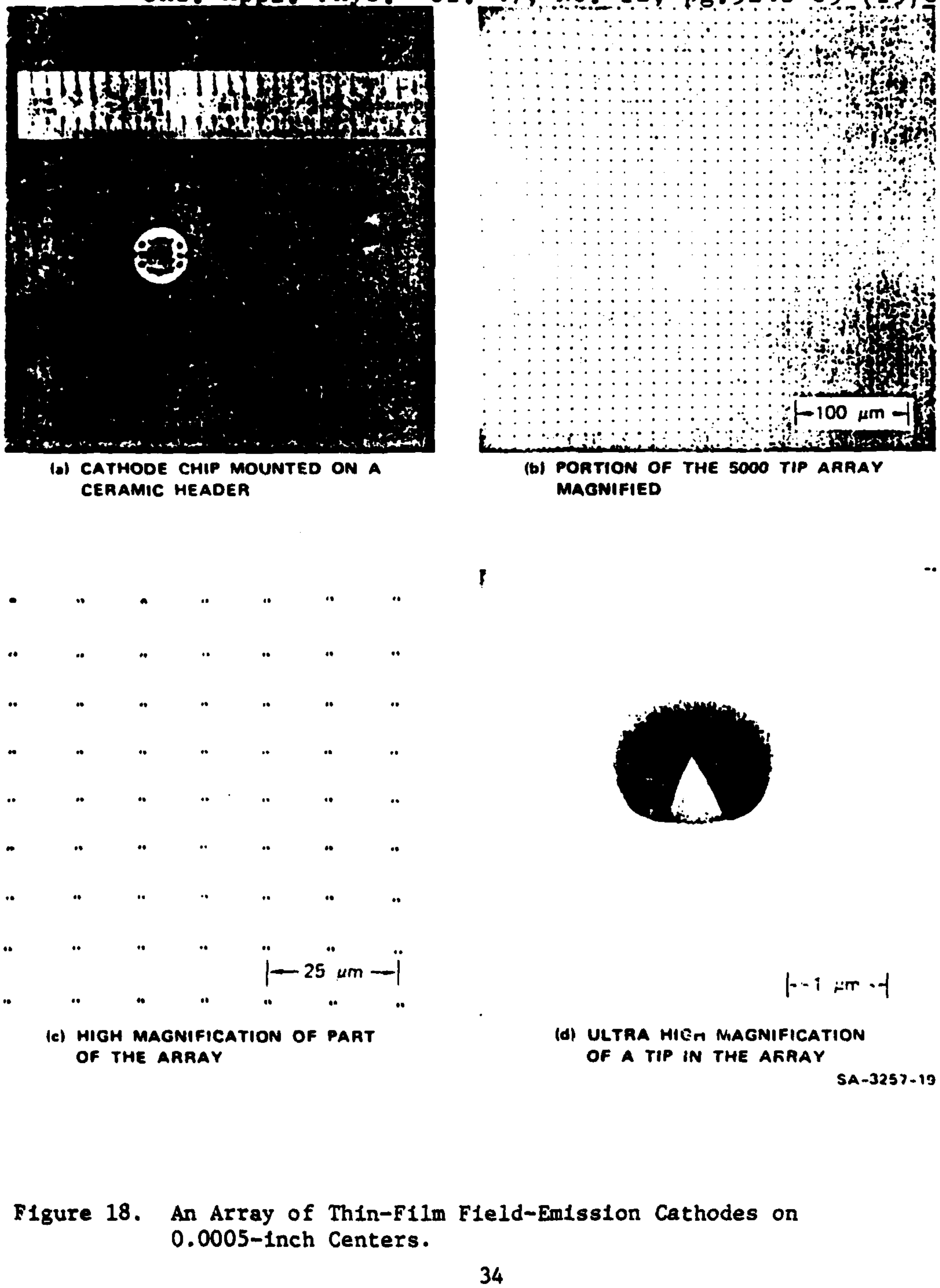




Reprinted from October 14, 1971 issue of MACHINE DESIGN

Figure 17. Spring Driven Ejector System.

I. Brodie, C.A. Spindt / (From Reference 3).
Jnl. Appl. Phys. Vol. 47, No. 12, pg.5248-63 (1976)



(a) CATHODE CHIP MOUNTED ON A CERAMIC HEADER

(b) PORTION OF THE 5000 TIP ARRAY MAGNIFIED

(c) HIGH MAGNIFICATION OF PART OF THE ARRAY

(d) ULTRA HIGH MAGNIFICATION OF A TIP IN THE ARRAY

SA-3257-19

Figure 18. An Array of Thin-Film Field-Emission Cathodes on 0.0005-inch Centers.

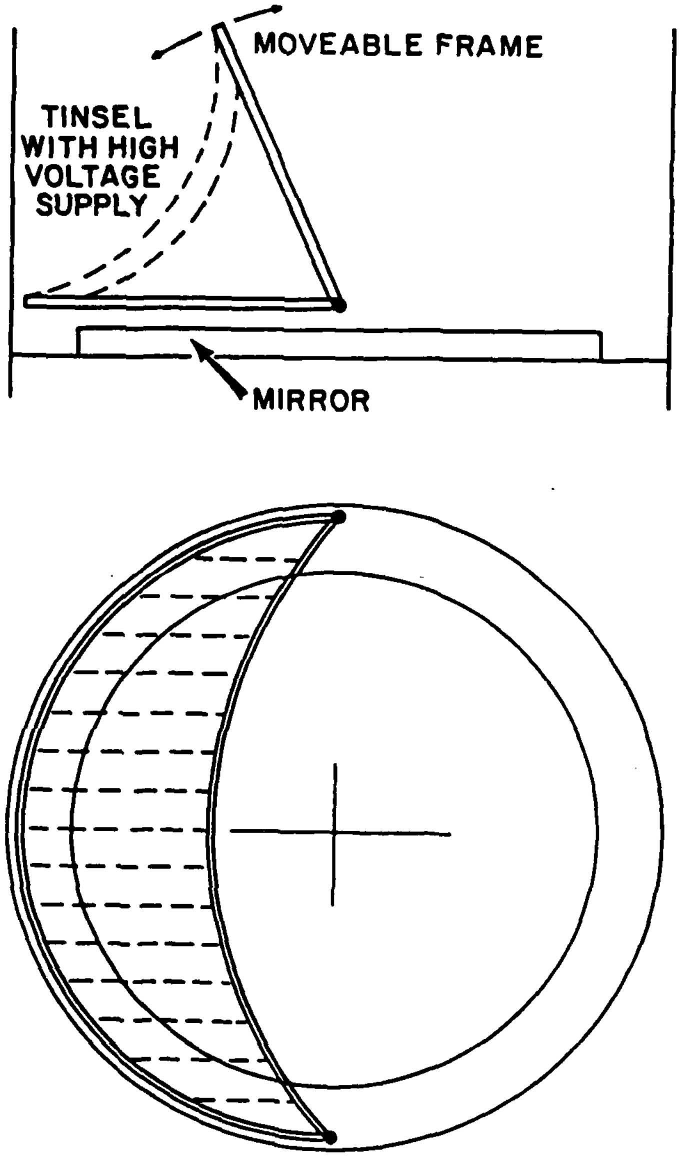


Figure 19. Schematic Drawing of Electrostatic Protection System for Use during Outgassing Processes.

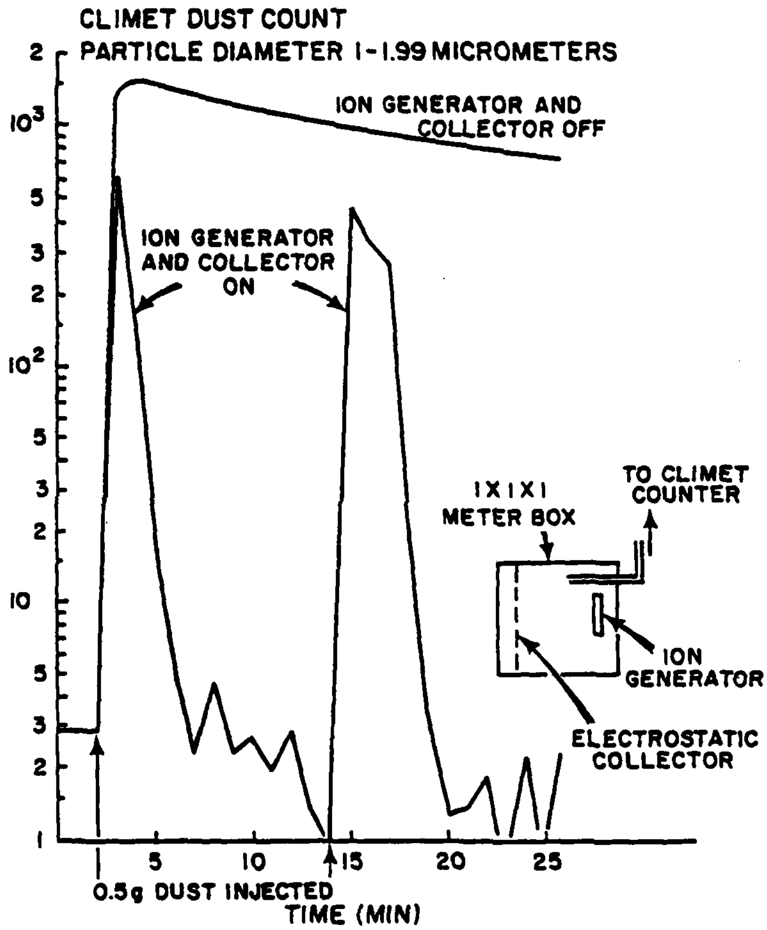
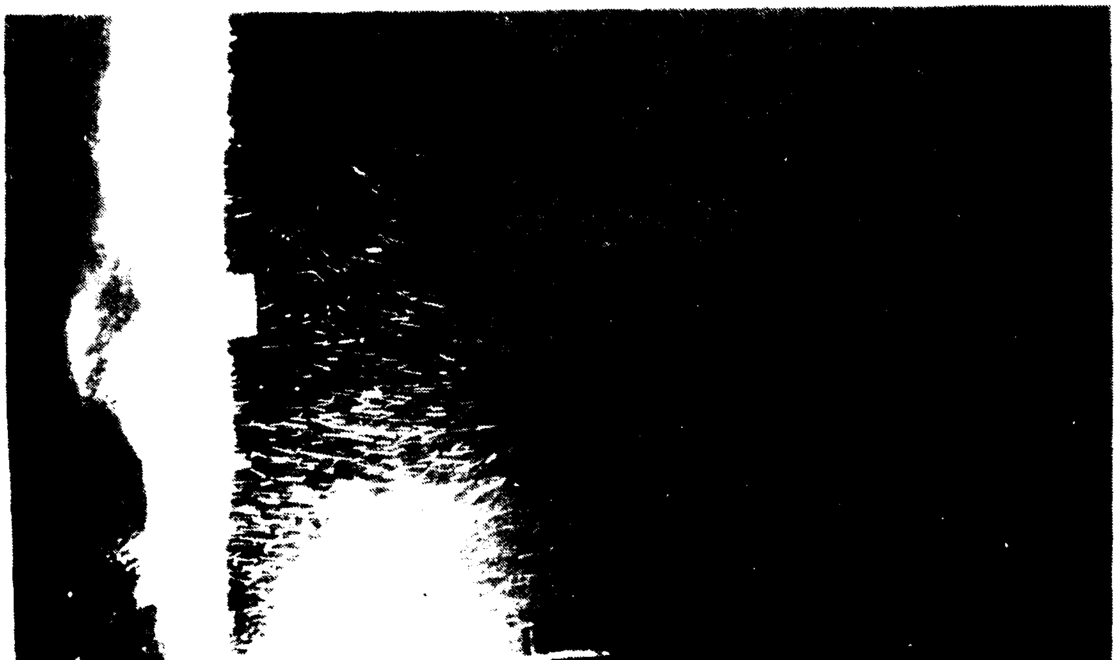


Figure 20. Test Results Dust Reduction with Ion Generator and Collector.

a. OFF



b. ON

Figure 21. Electrostatic Dust Ionization/Collection System: a. OFF; b. ON.

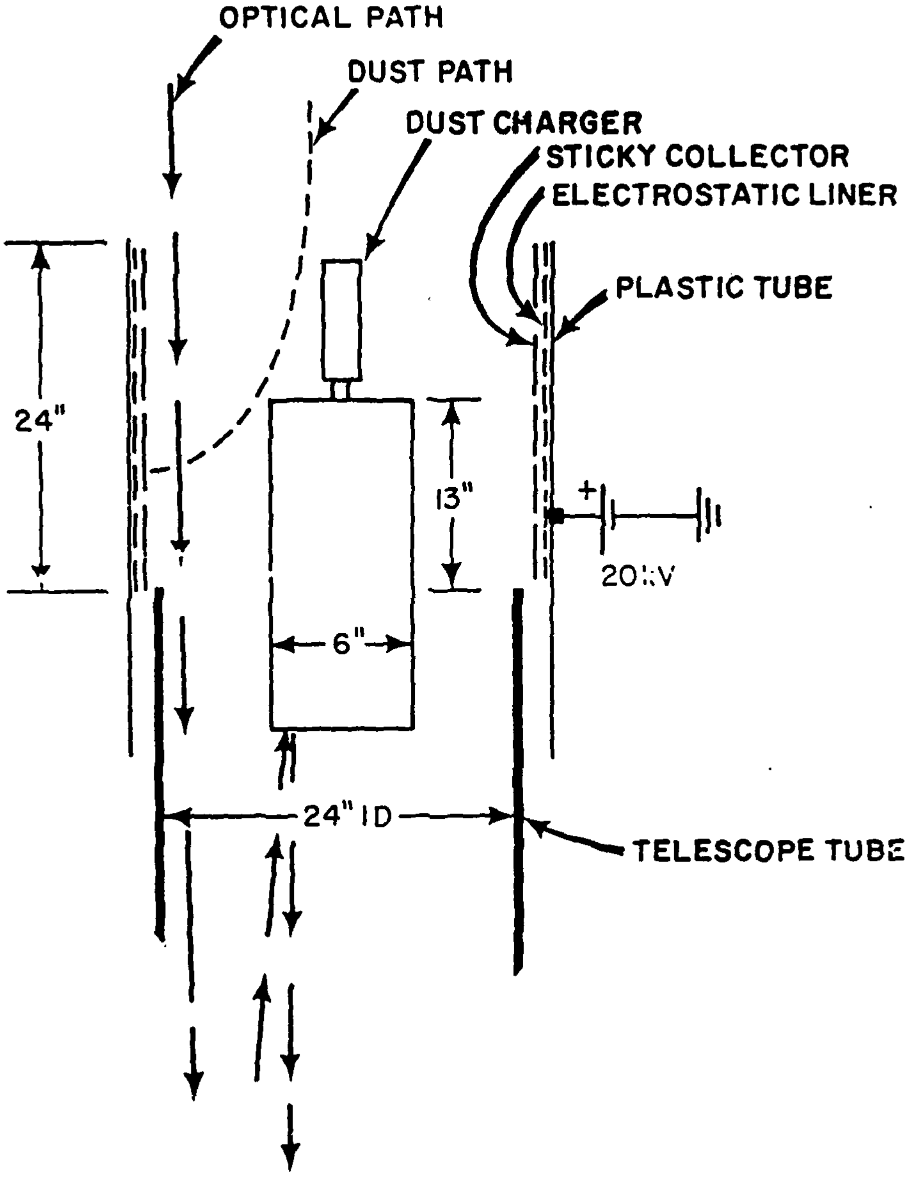
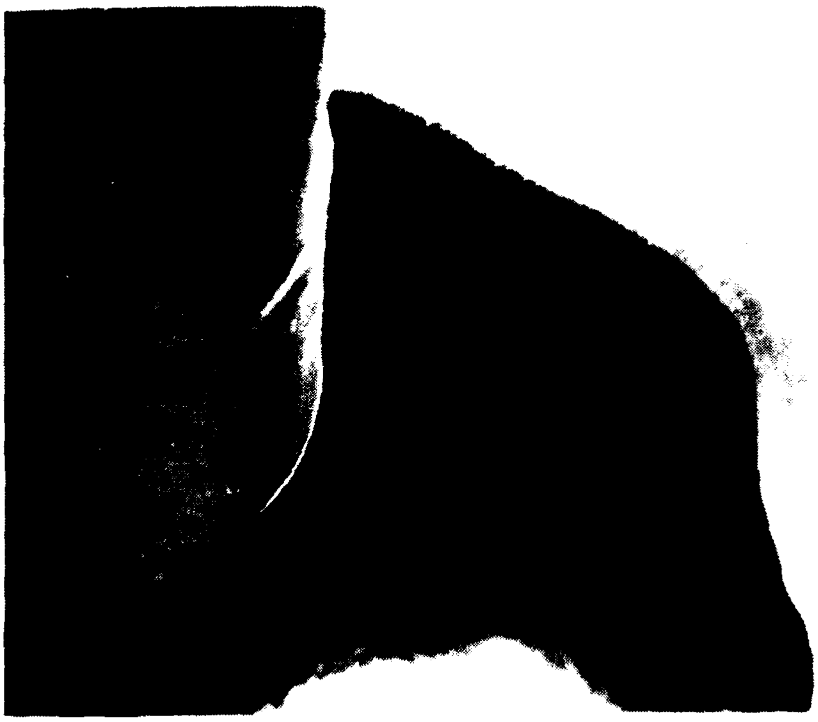


Figure 22. Schematic Drawing of Electrostatic Dust Collector for 24-inch Astronomical Telescope.

a. OFF



b. ON

Figure 23. Electrostatic Dust Ionization/Collection System:
a. OFF; b. ON.

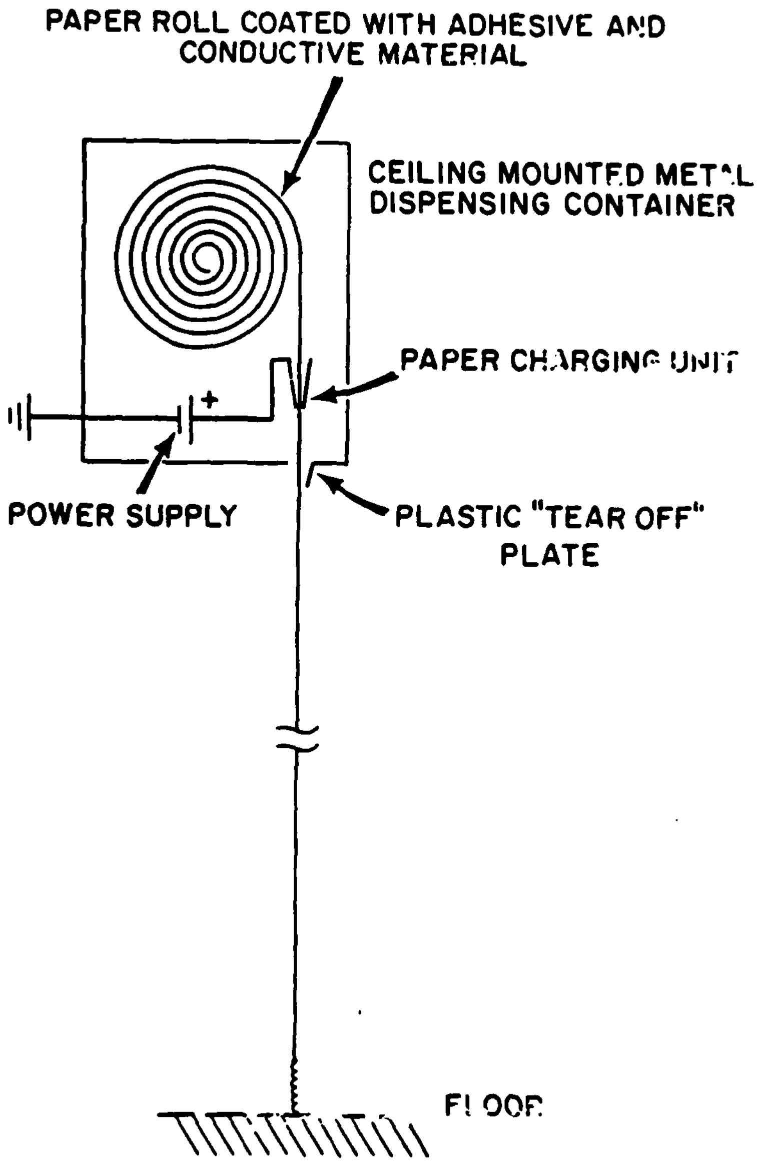


Figure 24. Schematic Drawing of Electrostatic Dust Collection System.

(This system was not developed on a federal contract and all rights are reserved to the inventor and the University of Arizona. A patent disclosure has been supplied to the University Vice President for Research. Inclusion of this drawing in a contract report does not imply any rights to use this technology without written permission of the University or its agents.)

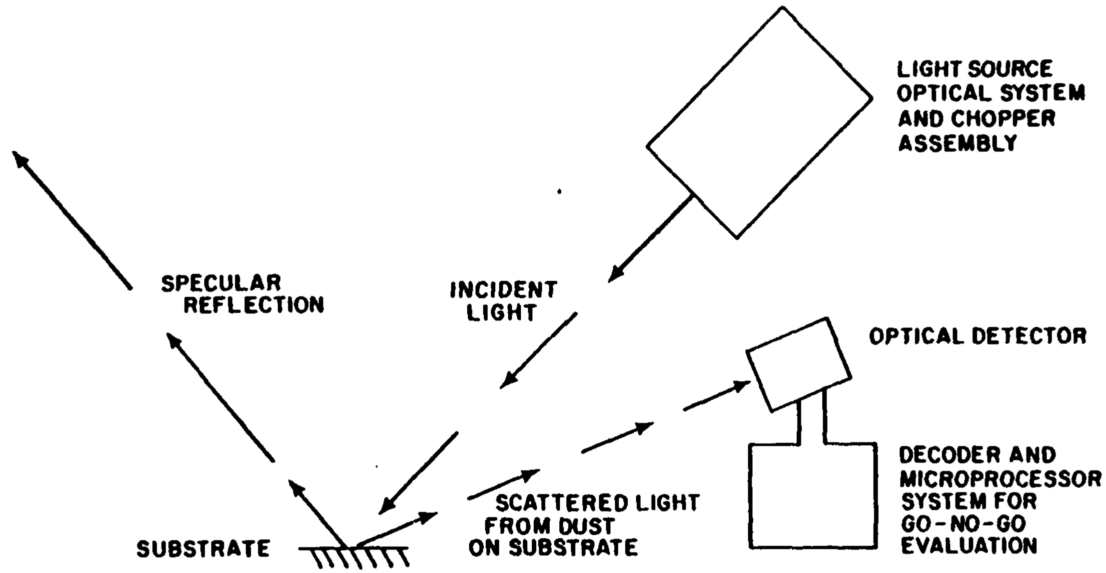


Figure 25. Schematic Drawing of Optical Dust Monitoring System.

Appendix A

ELECTROSTATIC DUST PROTECTION FOR OPTICAL ELEMENTS

by

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[Submitted to APPLIED OPTICS]

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INTRODUCTION

In an earlier publication [A1] we discussed some very elementary technology for protection of optical elements against soiling by dust or smoke. Since that time the program has developed in two directions:

1. Systems for high power laser elements where there is no possibility of any opaque element in the beam itself.

2. Apparatus for use with conventional astronomical telescopes where advantage can be taken of secondary mirror holders and associated spider structures to support dust rejection devices.

LASER PROTECTION TECHNOLOGY

Figure A1 shows a system designed for a 30 cm laser mirror where the beam power level precluded any structure in the optical area itself. The design of the electrostatic repulsion system followed the needle-screen array technology discussed in Reference A1. It should be noted that the needle to needle distance, the needle to screen spacing and the screen opening dimensions are all critical if best performance is to be obtained.

This system normally operates at some -20 kV and 5 mA DC. In Figure A2, we show the system set up for airflow tests where an ammonium chloride generator was used to allow visualization of the flow patterns. In the upper photograph, the high voltage was off, while in the lower photo the power was on and the smoke, at 300 FPM (91.5 m/min), was repelled.

For another test the protection system was set up in the horizontal position in a 1 x 1 x 1 meter box with an internal fan to provide air circulation. Figure A3 shows Arizona Road Dust (AC Fine) falling toward the mirror with the power off and on. When the power was on, the dust was repelled. In this experiment we noted the repelled dust was actually deposited on the walls of the chamber and held by electrostatic attraction. This suggests that the electrostatic repulsion system will repel dust and actually remove it from the ambient air.

In another experiment, we replaced the mirror with a 30 cm glass disc and masked one-half of the glass with a paper cover. The dust box was closed, AC Fine dust was injected, and then circulated by the internal fan. When the power was off there was a heavy dust coating; with the system on, only a few large (100 micrometer) clumps of dust were found on the mirror. The experiments were repeated with oil vapor generated by a medical nebulizer. Once again, the electrostatic system protected the optical surface and removed the oil particulates by charging and forcing them to deposit on the walls of the chamber.

For one last test, the system was set up in the open laboratory environment with a preweighed microscope slide on the 30 cm glass plate and a similar microscope slide in an "unprotected" area. Some six tests were run over a period of 24 hours where the difference in dust collection on the protected and unprotected slides was measured by weighing on a microbalance. There was an average 96.3% reduction in dust on the protected slide; the unprotected slide was covered with a variety of small and large particulates and a significant quantity of lint. In contrast, the protected slide was free of lint, and the only particles that could be observed were rather large (e.g., 100 micrometers) particles that could not be repelled by the electrostatic fence.

We feel that systems of this type can be designed or adapted for a wide variety of laser systems where beam power levels preclude any opaque objects in the beam. The electrostatic fence need not surround the mirror; we have developed pusing units that simply keep dust, smoke and fume out of optical containers or clean room facilities.

TELESCOPE PROTECTION SYSTEMS

A typical Cassegrain telescope system is exhibited in Figure A4, where protection is provided to the primary and secondary mirror by an ion generator mounted on top of the secondary mirror driver and a dust collector on the inner side of the optical tube, out of the actual light path. We have made use of felted materials coated with silicone oil for dust collection. Silicone oil has a very low vapor pressure, so that there is no danger of oil evaporation soiling the mirrors when the system is off. Silicone fluids may not be the optimum material for oiling the collector in that they are not very sticky and there may be a problem with field induced ejection of oil droplets from the collector. We have been in contact with a major manufacturer of adhesives, and testing of these materials will take some time. The results will be reported in a later publication.

To obtain numerical data on the rate at which a system of this type could remove dust from a closed environment, we obtained a Climet Company dust counter, on loan from Motorola SPD in Phoenix, Arizona, through the courtesy of Mr. D. Tolliver. Figure A5 displays the results of an injection of approximately 0.5 gm dust (AC Fine) with the ionization and collection systems off and on. It is clear that with the electrostatic systems "on" the dust was quickly removed. We anticipate that systems of this type will find wide application in clean rooms or optical facilities where dust deposition might interfere with operations.

One full scale test of the system shown in Figure A4 is in progress at the 24-inch Smithsonian telescope on Mount Hopkins, south of Tucson. After one month of operation, there is no evidence that the sticky collector is building up a charge that would interfere with the operation of the ionizer. A monitor plate has been set up to detect any field induced evaporation from the oil wetted collector, or deposition of dust on the primary mirror.

SYSTEM ANALYSIS

It is of some interest to examine how a system like this might work for a very large (8 meter) telescope of the type that might be deployed from the Space Shuttle. There is no air to affect the motion of dust particles, but protection may be needed against micrometeorites and gases vented by the attitude control system on the spacecraft.

The apparatus itself is shown dimensionally in Figure A6. The center post, marked V_a, is in the optical shadow of the secondary mirror driver unit and would be designed to generate the electrons that will be used to charge incoming dust particles. The simplest technology for this purpose might involve the well known field emission phenomena where electrons are extracted from a metal by a strong external field gradient. These electrons, with energies as high as 20 keV, would not be suitable for charging particulates because of the danger of secondary emission. We suggest that the thin film field emission cathode system developed by Spindt and his associates would be more suitable for this application in that it can deliver appreciable currents (mA) with applied potentials of some 100 V [A2].

We might expect that the field gradient between the inner and the outer elements (V_a , V_b, in Figure A6) would charge nonconducting particles by induction. This would serve to increase the charge provided by the 100 eV electrons from the field emission source. In the analysis below it will be shown that the charge level of the particles is a critical factor in insuring effective collection before the dust can reach the optical components.

In this system the outer element identified as V_b in Figure A6 is composed of a conducting material covered with the same sticky collector material shown earlier in Figure A4. For operation, V_b is held at a high voltage of a polarity opposite to that of V_a with the objective of developing a strong potential gradient in the space between the two electrodes. Any dust or hydrocarbon molecules (from the propulsion system) that enter the protection device will be drawn to the collector and thereby removed from the optical path. Eventually, the collector material will have to be replaced but experience in the laboratory indicates that collectors can absorb relatively large amounts of dust particularly when they are recoated with silicone oil on a periodic basis. This recoating can be done while the high voltage is "on" by simply spraying a fog of oil into the system; the oil droplets will be charged and drawn to the collecting material.

To evaluate the potential ability of the system for dust collection, we make the usual assumption of an infinite cylindrical geometry. For this system the field gradient and potential difference may be written as:

$$E\left(\frac{\text{Volts}}{\text{Meter}}\right) = \frac{Q}{2\pi\varepsilon_0 \ell}\left(\frac{1}{r}\right)$$

$$V \quad (\text{Volts}) = \frac{Q}{2\pi\varepsilon_0 \ell}\,\ell n\ (b/a) \qquad \text{(A1)}$$

where Q is the charge per unit length in the system, a and b are the inner and outer radii (see Figure A6), and ε_0 is the permittivity constant.

If a and b are known, E can be written as

$$E = \frac{\left(V_a - V_b\right)}{\ell n\ (b/a)} \left(\frac{1}{r}\right). \tag{A2}$$

Here, E is a function of $\frac{1}{r}$ but we choose as a worst case $r = b$ to evaluate the dust collection system.

Assuming an incoming dust particle to have a mass m and velocity v, the electrostatic deflection in the collection system can be written as

$$\frac{QE\ell^2}{2mv^2} \text{ (meters)} \tag{A3}$$

Here, Q is the particle charge. For the case at hand we require that

$$b \leq \frac{QE\ell^2}{2mv^2} \quad \text{or} \tag{A4}$$

$$b^2 \leq \frac{Q\ell^2}{2mv^2} \left(\frac{V_a - V_b}{\ell n(b/a)}\right) \tag{A5}$$

To obtain numerical values we use the dimensions of Figure A6 and solve for mv^2/Q (the dust particle characteristics) in the form

$$\frac{mv^2}{Q} = 0.75 \left(V_a - V_b\right) \frac{kg\ m^2}{C\ s^2} \tag{A6}$$

If we consider a 1 micrometer silica particle with a charge [A3] of $1.6 \cdot 10^{-17}$ coulomb, the ratio $\frac{Q}{m}$ ($\frac{C}{Kg}$) has the value $1.52 \cdot 10^{-2}$ and the limiting particle velocity, assuming that $(V_a - V_b) = 40$ kV, is 21.3 m/s. For a 10 micrometer particle with a charge of $1.6 \cdot 10^{-15}$ coulomb, the ratio $\frac{Q}{m}$ has the value $1.52 \cdot 10^{-3}$ and the limiting velocity is 6.76 m/s.

This level of performance should be effective in removing the dust and/or hydrocarbons associated with outgassing from the spacecraft, but there is the added question of high speed micrometeorites. If this is a problem, we would suggest the installation of a larger field electron emitter, with the idea of enhancing the charge on the particles to the limit suggested in Reference A3. For a 1 micrometer particle the charge would be 10^5 electrons or $1.6 \cdot 10^{-14}$ coulomb which yields the limiting velocity of 673.6 m/s. A similar calculation for a 10 micrometer particle leads to a limiting charge of $1.6 \cdot 10^{-12}$ coulomb. This, in turn, leads to an allowed velocity of 213.8 m/s.

Figure A7 shows a plot of the limiting particle velocity in the form of

$$v \le 173.2 \left(\frac{Q}{m}\right)^{1/2} \tag{A7}$$

If this level of protection is not adequate, the best solution might be an extension of the electrostatic collection system by means of a simple mechanical boom that could be deployed after the telescope has been placed in orbit. An examination of the relation between

$$v, \ell, Q, b \quad \text{and} \quad \left(V_a - V_b\right) \tag{A8}$$

indicates that v increases directly with ℓ and b but only as the square root of Q and $V_a - V_b$. It does not appear practical to change b and we suggest that consideration be given to increasing ℓ for improved dust protection.

It is of some interest to repeat the analysis for the conditions that might exist in a telescope designed for use in an earth based observatory. In this case, the collection problem is complicated by the effect of ambient air on the motion of the dust particles. Stokes theory indicates that the settling velocity under gravity will increase as the square root of the particle diameter [A3]. A typical settling velocity for a 1 micrometer silica particle would be about $3 \cdot 10^{-3}$ m/min.

The maximum velocity for a charged particle in an electrostatic field has been measured by many experimenters. For a 1 micrometer particle 1.5 m/min might be a typical value, while for a 15 micrometer particle the velocity would be some 9 m/min with no further increase for larger particle sizes [A4].

To see how these numerical values will affect the particle collection process we turn to the system shown in Figure A6. The time for a particle to fall the length of the collection unit may be written as $\Delta t_1 = \ell/v_z$ where v_z is the Stokes fall velocity for the particle involved. The time for the particle to travel a distance b to the collector will be given at $\Delta t_2 = {}^{b}/v_r$ where v_r is the maximum velocity of a charged particle in an electrostatic field. For effective collection, the condition $\Delta t_1 \gg \Delta t_2$ must apply, and we can write the general relation in the form

$$b \ll \ell \left(v_r/v_z\right).$$

If we test this formula for the telescope protection system of Figure A4, the numerical values (for a 1 micrometer particulate) are $v_z = 3 \cdot 10^{-3}$ m/min, $v_r = 1.5$ m/min, $\ell = 7.35$ m and $b = 3.8$ m. In this case, the collection formula is easily satisfied

$$\ell \left(v_r/v_z\right) \gg b \text{ yields } 3675 \gg 3.8 \,.$$

For an 80 micrometer particle, the situation is not as satisfactory. The collection formula yields the result $\ell\left(\frac{V_r}{V_z}\right) = 6.44$, while the value of b is 3.8. These results suggest that collection will be almost 100% effective for small (under 25 micrometer) particles, the type that are normally levitated by the wind. Protection against larger particles must involve electrostatic and mechanical systems (e.g., dust shields).

If we apply the same criteria to a system similar to that shown in Figure A4 where b = 0.36 m, we find that for 1, 10 and 80 micrometer particulates, the collection formula results are:

Particle Diameter (micrometers)	$\ell\left(V_r/V_z\right)$
1	305
10	23
80	0.52

Once again, we might expect very effective collection for 1 and 10 micrometer particles but more limited results with larger (80 micrometer) materials.

For an experimental test some 5.5 grams of AC Fine was dropped from a flour sifter into the system in Figure A4. The material reaching the bottom was collected on oiled paper and the collection efficiency was determined by weighing the oiled paper before and after collection. There was considerable scatter in the data because of the tendency for the smaller particles to drift about, but the average efficiency in several tests was between 80% and 90%.

The material that did get through the collector with the field on was composed almost entirely of rather large particles and clumps of material that may not have been broken up by the flour sifter. Dust particles are known to acquire a charge when broken up by a metal sifter [A5] and this may have enhanced the effect of the collection system.

One last experiment involved the use of lint from a home clothes dryer instead of AC Fine. In this case collection was 100% effective when the field was on. This might have been expected; the low density and cylindrical shape of lint particles will insure that they fall quite slowly giving the electrostatic field time to sweep them out of the system.

CONCLUSIONS

We suggest that electrostatic techniques offer the opportunity to protect optical elements against dust and vapors (e.g., smoke) without excessive use of power or interference with the operation of the optical system itself.

REFERENCES

A1. Hoenig, S. A. "Electrostatic Techniques for Protection of Optical Components in Dusty Environments," App. Optics, 19, No. 5, pp 694-697 (1 March 1980).

A2. Davis, C. N. Aerosol Science, Academic Press, New York, pg 63 (1966).

A3. Strauss, W. Industrial Gas Cleaning, 2nd ed., Pergamon Press, New York, pgs 183, 443 (1975).

A4. Gallo, C. F. "Classical Electrostatic Description of the Work Function and Ionization Energy of Insulators," IEEE Trans. Ind. Appl., 1A-12, No. 1, pg 7 (January/February 1976).

A5. Kunkel, W. B. "The Static Electrification of Dust Particles on Dispersion into a Cloud," Jnl. Appl. Phys., 21, pp 820-832 (1950).

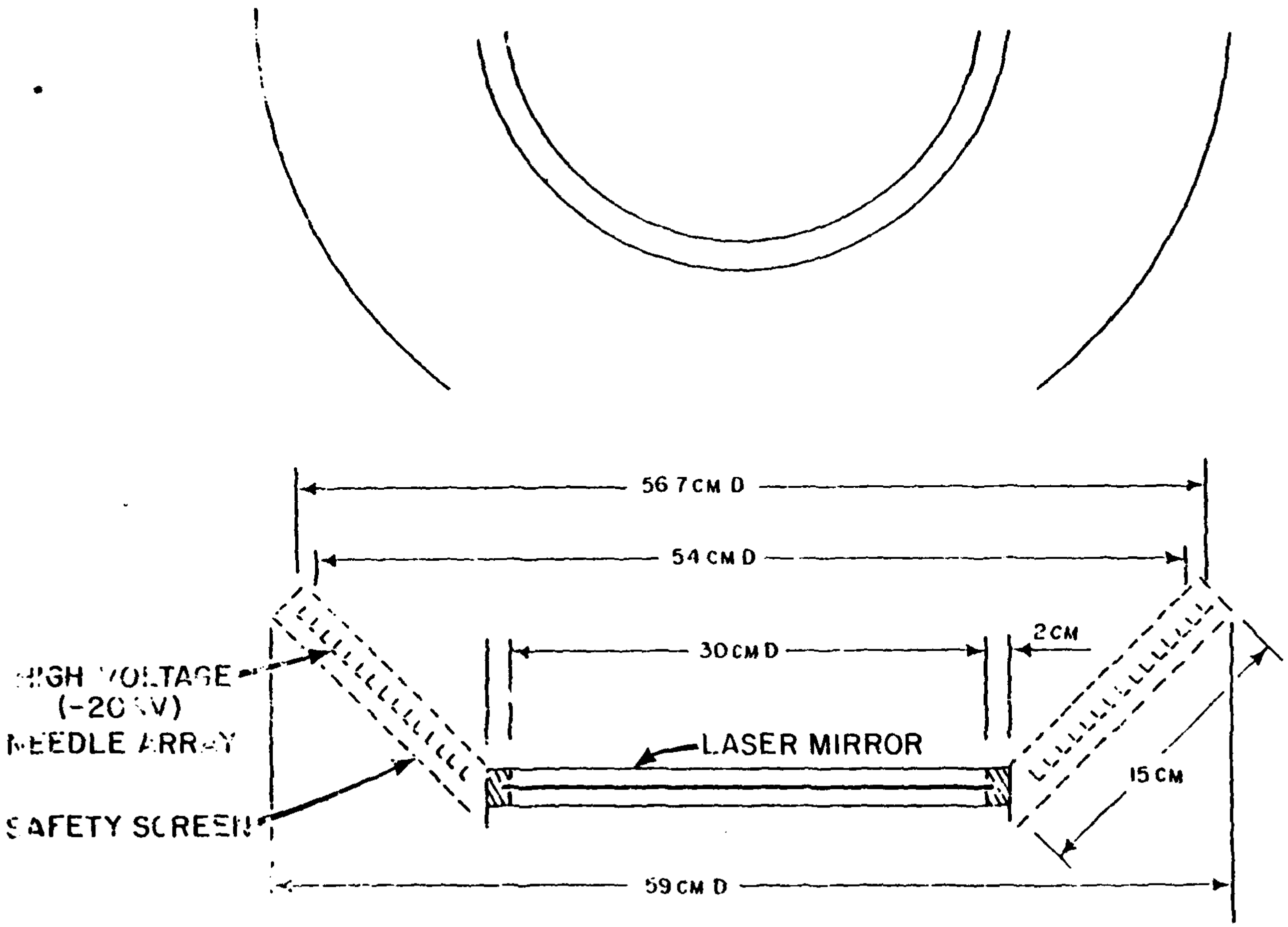
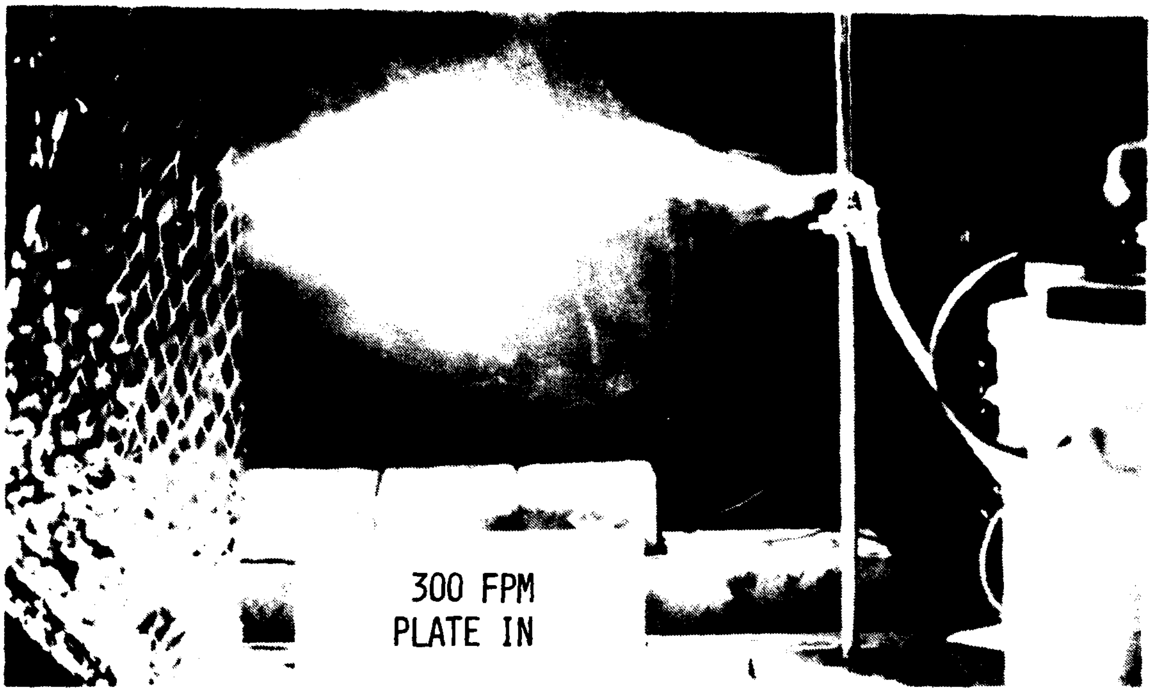
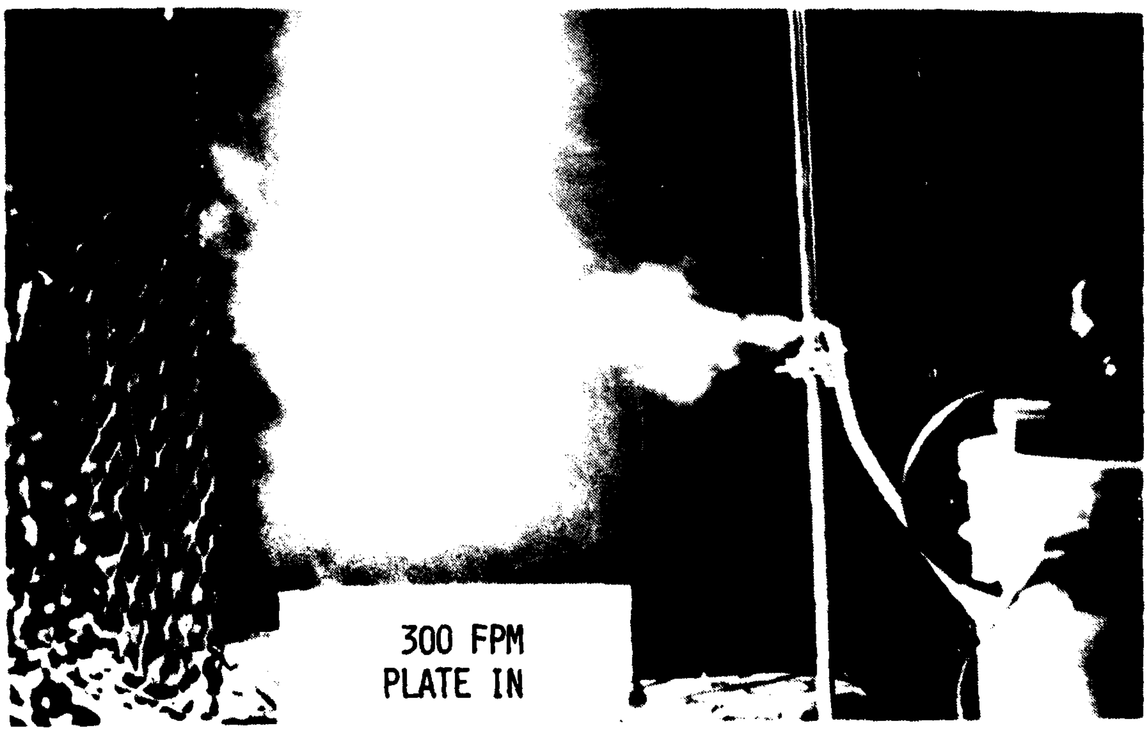


Figure A1. Schematic Drawing of Electrostatic Dust Repulsion System for 30 cm Mirror.

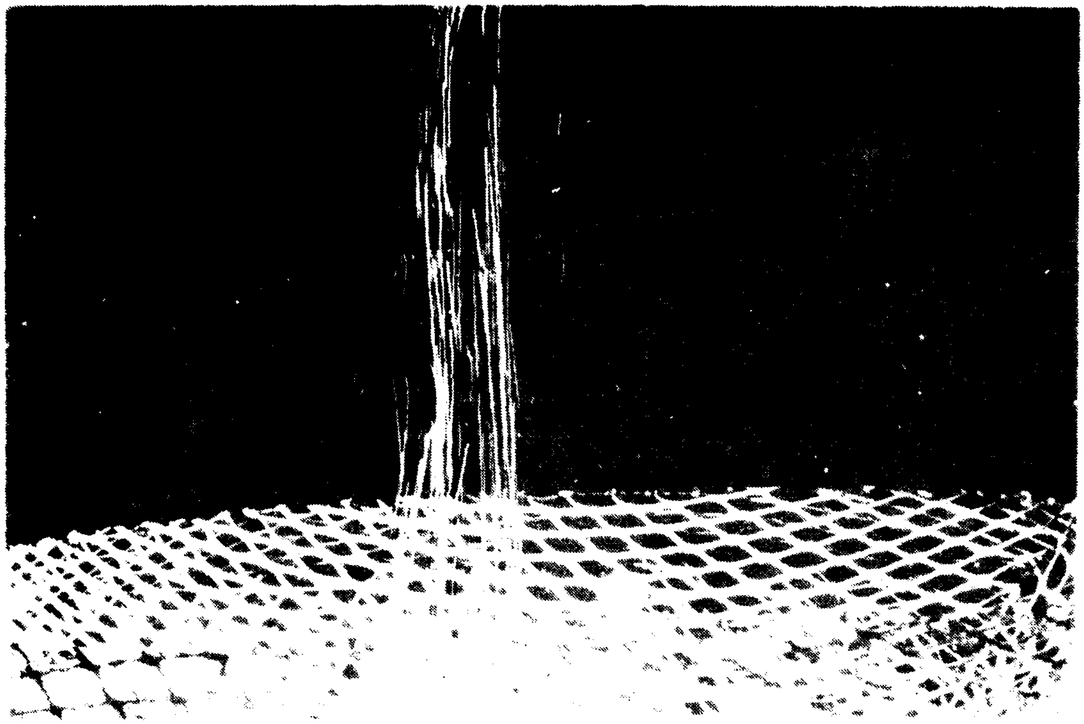


a. OFF



b. ON

Figure A2. Electrostatic Repulsion System: a. OFF; b. ON.



a. OFF

b. ON

Figure A3. Electrostatic Repulsion System: a. OFF; b. ON.

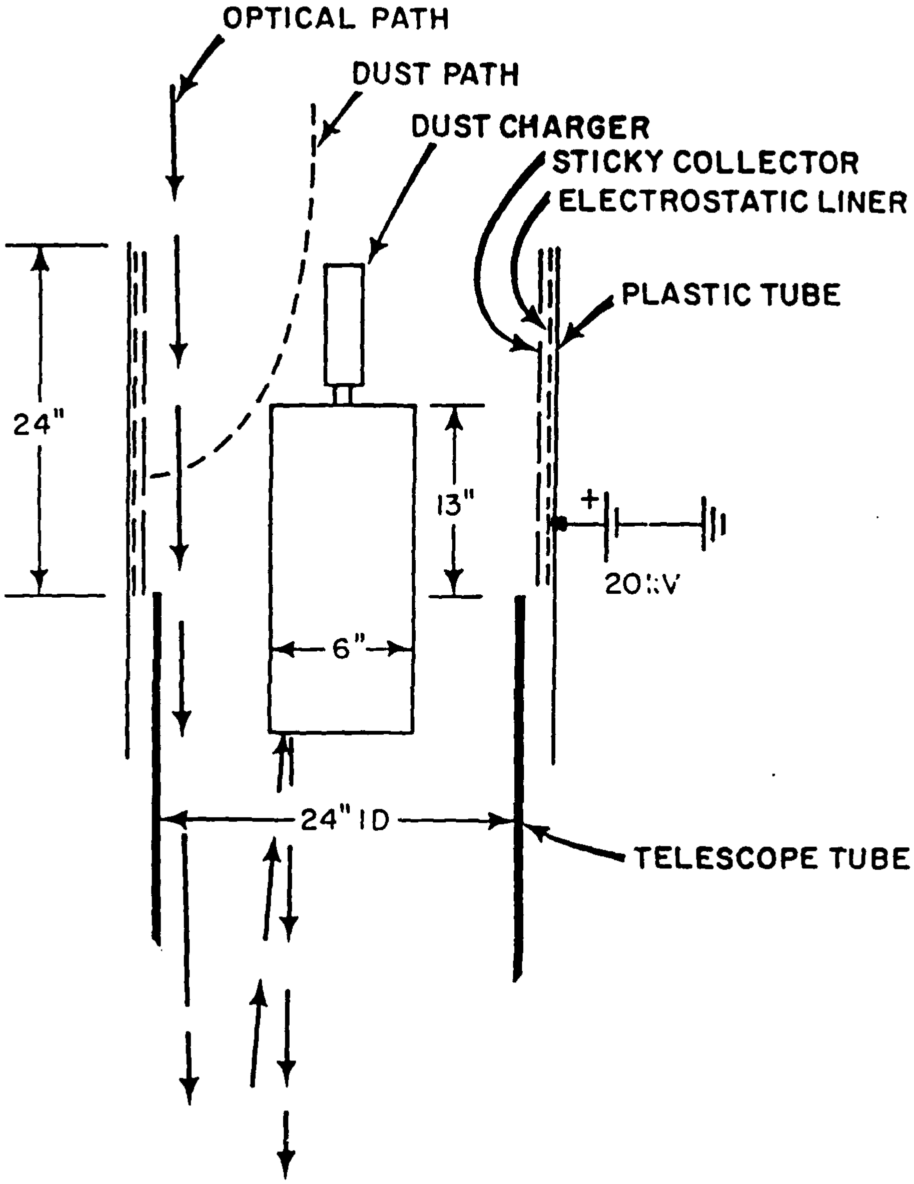


Figure A4. Schematic Drawing of Electrostatic Dust Collector for 24-inch Astronomical Telescope.

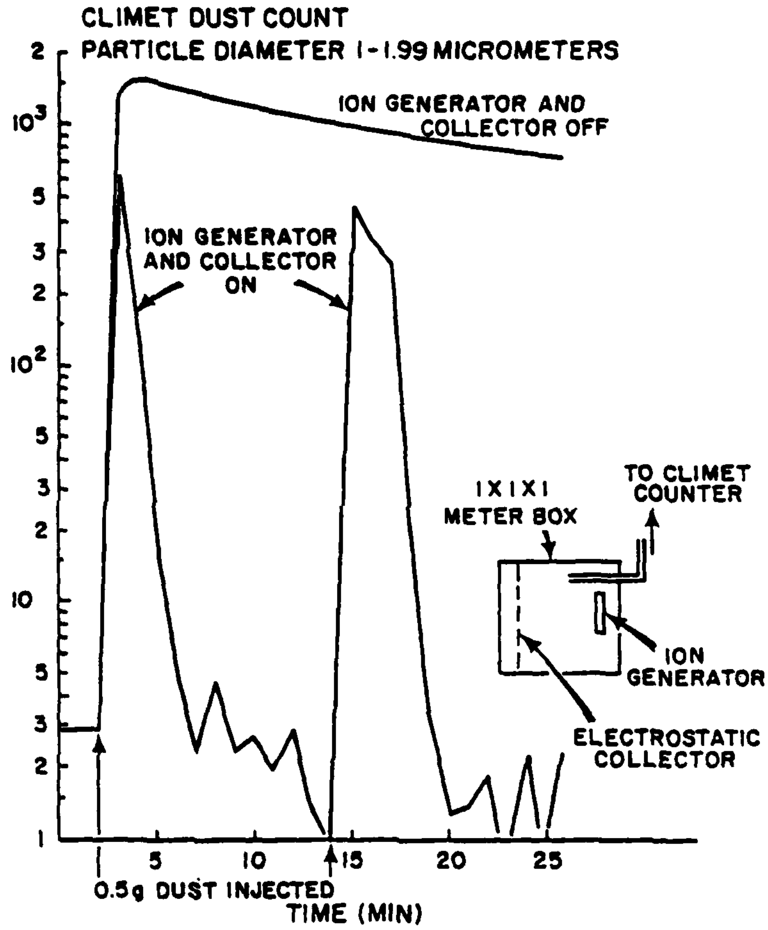


Figure A5. Test Results Dust Reduction with Ion Generator and Collector.

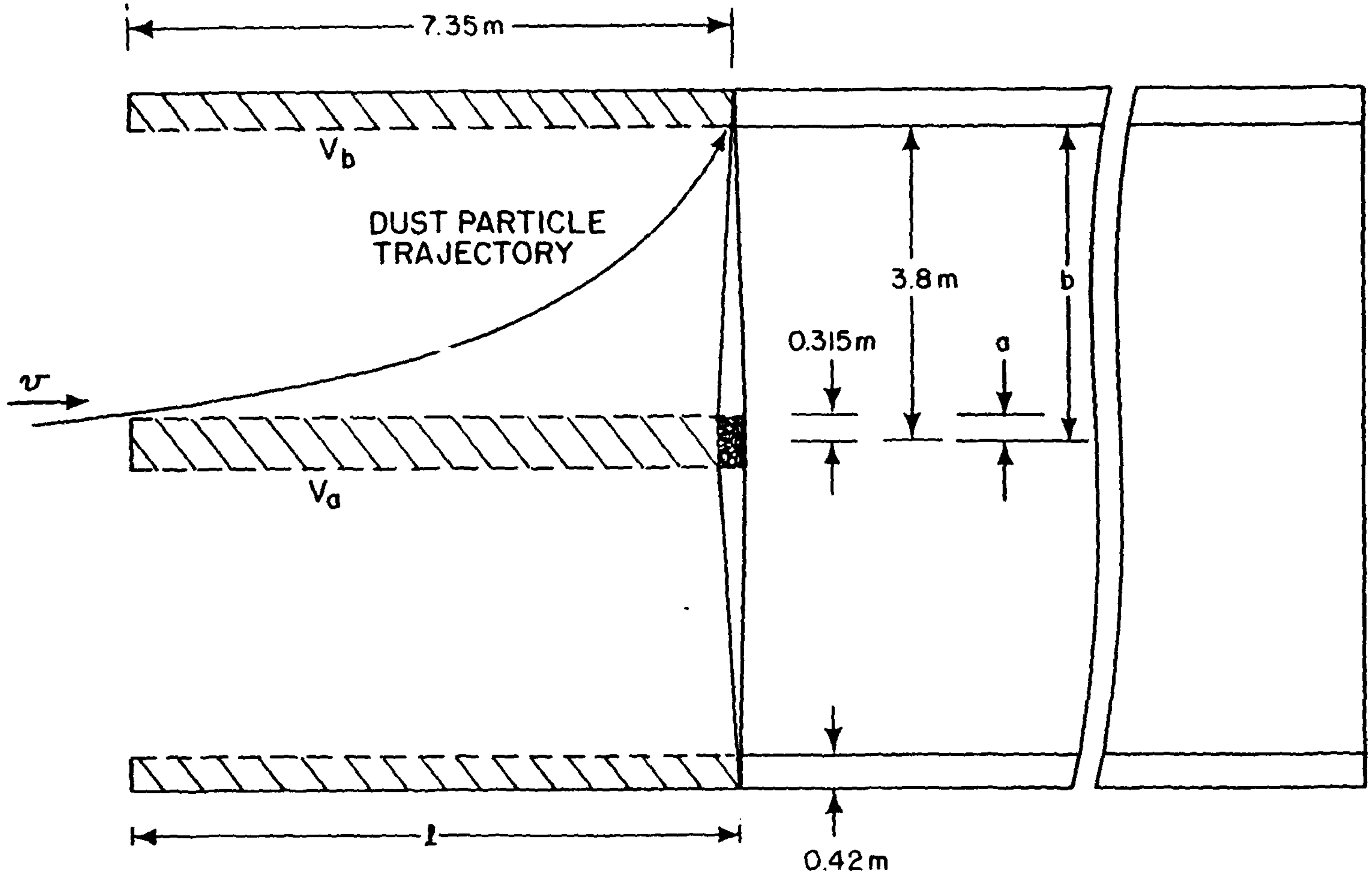


Figure A6. Schematic Drawing of Electrostatic Protection System for 8 Meter Telescope.

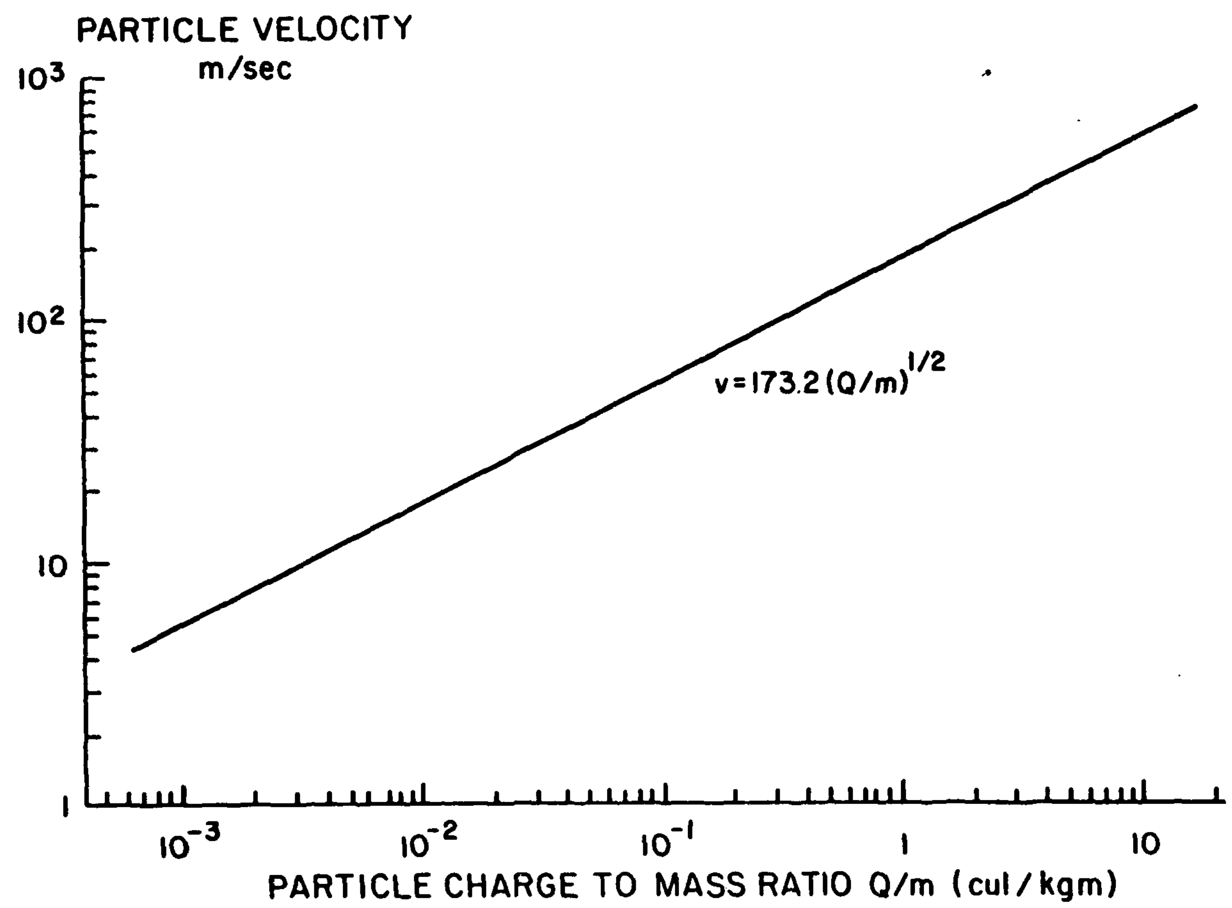


Figure A7. Limiting Particle Velocity for Collection in Terms of Charge to Mass Ratio.